Second Edition

Building Materials

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To
MOLLY and RAJU

Contents

Preface

This book was first published in 2005. Since then, rapid progress has been made in the use of modern building materials. The most notable changes in the subject that are dealt within this book are

1. Chapter 13 Revision of IS 10262 (1982) code on concrete mix design to IS 10262 (2009)
2. Chapter 14 Large advances made in concrete construction and repair chemicals
3. Chapter 20 Extensive use of aluminium in building construction

Accordingly, only Chapters 13, 14, and 20 have been revised.

P.C. Varghese

Preface to the First Edition

The traditional practice in Civil Engineering education has been to teach Building Materials and Building Construction during the early years of the students' academic career. The emphasis of these courses was not on teaching the details of the subject but on making the students familiar with the local materials and local construction practices, so that they can observe and get interested in building activities taking place around them. My aim in this text is primarily to create such an interest in the students and enable them to develop the twin habits of keen observation and self-study which will help them in all walks of life.

In recent times, as more and more emphasis is being placed on analysis and design, some universities have renamed the subject of Building Materials (perhaps for modernity) as Engineering Materials and Construction Materials. Others have substituted it by Material Science or Building Physics, molecular structure of the material being given more emphasis than material behaviour.

It is fortunate that many other institutions have realised that Civil Engineering education in India should be practice-oriented, especially as, in contrast to western countries, we have to catch up with a great deal of construction activities in housing and infrastructure. Practice-oriented teaching of Building Materials is again becoming popular is many universities and institutions.

It also happens that in most colleges, Building Materials is taught by junior staff members with little or no field and teaching experience. The students who attend these courses are also junior students not used to self-study. What is required for them is only an introduction to the subject and not the technical details. Under these circumstances, I felt that there is a need for a simple textbook on the subject, as most of the books available in the market are for students preparing for their professional examinations.

This book has been written in a teacher-friendly manner to enable the teachers to prepare for their classroom lectures. Each chapter deals with only one important topic meant for one or two lecture hours. The students will also find revising the subject easy with the review questions given at the end of each chapter. References to IS codes will make the study professional.

I hope the book will prove useful to the teachers teaching the subject and also encourage the young students in the habits of keen observation of things around them and also the art of self-study.

P.C. Varghese

Acknowledgements

After authoring books in Civil Engineering meant for senior students and professionals, I decided to write this book on Building Materials for junior classes subsequent to the experience I had while teaching the above subject (along with the staff members assigned for the subject) to the second semester students in Civil Engineering at the College of Engineering, Guindy (Anna University).

I am indebted to two of my younger grandchildren, Ashwin and Nisha, who inspired me to see that there is a need for separate books to be written for the younger generation of teachers and students. I am thankful to all those who have encouraged me in this endeavour.

I appreciate the help I received from Dr. S. Greeshma, Department of Civil Engineering, College of Engineering, Guindy (Anna University) for proofreading the manuscript of the book and using it also for lectures to test its usefulness for classroom lectures.

I am thankful to Dr. V. Tamizhselvi for helping me in the initial preparation of the book. My thanks are also due to Mrs. Rajeswari Sivaraman for word processing my handwritten manuscript and to Mr. R. Ramadas for preparing the initial drawings.

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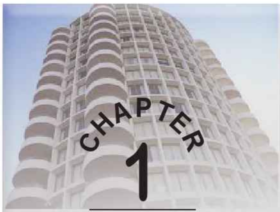
P.C. Varghese



CHAPTER 1

Building Stones

1.1 INTRODUCTION

In many places, as in hilly regions, stones are more freely available than clay bricks. They occur naturally and need not be manufactured so that stone masonry becomes cheaper than brick work. From early days, even before the bricks were invented by the humans, stones were used to build dwellings. Old roads with heavy traffic were also paved with stones. In addition, man learnt to build beautiful monuments with natural stones. They were used for ornamental work in important structures like temples and places of assembly. Stones are more permanent than most of other natural building materials like wood. Most of the prehistoric monuments that remain even today are made of stones. Stones were prefered before the advent of concrete for heavy engineering constructions like bridge piers, harbour walls, seaside walls, and they are still used for facing work, for tall buildings. In many situations, as in foundations of ordinary buildings which are liable to be flooded, the stonework is used instead of brickwork. Submerged bricks usually breakdown with time but the stonework remains stable. Today, stones form an important source of aggregates (both coarse and fine) for concrete. Thus, stone is an important building material that all civil engineers should be familiar with.

1.2 CLASSIFICATION OF ROCKS

The stones used for masonry construction must be hard, durable, tough and sound. It must be free from weathered soft patches of material, cracks and other defects which may reduce its strength and durability. Stones for building purposes must be obtained by quarrying from solid massive rocks and not by breaking boulders. The major classifications of the rocks are discussed here:

1.2.1 Geological Classification

1. ***Igneous rocks.*** They are formed by cooling of molten lava released during a volcanic activity. These stones are very strong and durable. Many of the temples of South India are made of igneous rocks. There are three types of formation of these rocks.
   (a) They can be formed by *volcanic action* where it solidifies above the earth. Basalt, Andesite, Trap and Rhyolite are examples of this type of formation.

(b) They can also solidify far below the earth's surface (*Plutonic*) and then exposed by errosion. Granite, Diorite and Gabbro are the igneous rocks formed due to this type of formation.

(c) They can also result from *major intrusions* dykes and sils. Quartz, Dolerite, Gneiss are examples of this type of formation. Gneiss is identified by its elongated platy mineral grains often in the presence of mica.

2. ***Sedimentary rocks.*** Limestones, Dolomite and Sandstones are examples of sedimentary rocks. They are formed by sedimentation in water followed by intense pressure which converts the sediments into rock.
3. ***Metamorphic rocks.*** Slates and marbles come under this group. They are igneous or sedimentary rocks which have been changed due to either pressure or heat or both. The following are some of the changes that can happen by this action.
   (a) Sandstone into quartzite
   (b) Limestone into marble
   (c) Shale into slate
   (d) Granite can change into gneiss under heat and pressure.

1.2.2 Physical and Chemical Classification

The physical classification of rosks is as follows:

1. Stratified rocks
2. Unstratified rocks
3. Foliated rocks (like the leaves of a book).

The chemical classification of rocks is as follows:

1. Silicious—consisting of quartz. sand, etc.
2. Argilacious—consisting of clay minerals.
3. Calcarious—consisting of carbonate of lime.

1.3 COMMON BUILDING STONES AND THEIR USES

A study of rock-forming minerals belongs to Geology. We will deal only with the various types of stones. As already stated, stones, depending on the type, can be used in buildings for masonry, flooring, roofing and paving roads as well as aggregates for concrete. We should have enough knowledge of Geology to identify rocks from their appearance and texture.

Some of the common stones found in India and their uses are as follows.

1. ***Granite*** (Igneous rock). It is used for heavy engineering works for bridge piers, columns, retaining walls, random rubble, foundation, dressed stonework and for coarse aggregates in concrete. They can also be cut into slabs and polished to be used as floor slabs and stone facing slabs.
2. ***Basalt and trap*** (Igneous rocks). They have the same use as granite. Deccan trap is a well-known stone of this group in South India.

3. ***Gneiss*** (Metamorphic rock). It is used in the same way as granite. It can be identified by its elongated platy minerals often mixed with mica.
4. ***Quartzite*** (Metamorphic rock). It is also used in the same way as granite but it is not used for ornamental work as it is brittle.
5. ***Marble*** (Metamorphic rock). It is used for ornamentation, flooring and stonefacing slabs.
6. ***Slate*** (Metamorphic rock). It is used for damp-proofing flooring and roofing
7. ***Limestone*** (Sedimentary). It is used for walls as coarse aggregates for concrete and also as a base material for cement.
8. ***Sandstones*** (Sedimentary). They are used for ornamental work and paving.
9. ***Laterite*** (Decomposed from igneous rocks). It can occur in hard and soft varieties. The soft variety is used for walls after curing while the hard variety is used for paving the pathways. They can also be formed as sedimentary rocks when it is called secondary laterites.

The stones used for various types of works are shown in Table 1.1.

Table 1.1 Uses of Stone for Masonry and Flooring

S.No.	Type of work	Stones used
1.	Heavy engineering works such as building bridge piers, breakwaters, monuments, etc.	Fine grained granite and gneiss
2.	Masonry work in industrial areas exposed to smoke and fumes	Granite, quartzite and compact sandstone
3.	Facing work of buildings	Marble, granite or sandstone
4.	General building work	Limestone and sandstone
5.	Carvings and ornamental works	Fine grained granite, marble and soft sandstone
6.	Fire-resistant masonry	Compact limestone and sandstone
7.	Floor pavings	Marble, slate, sandstone and granite
8.	In foundations of building in places with high ground water level.	Granite, quartzite

1.4 QUARRYING OF STONES

Good stones are obtained by quarrying from solid rock formations and not from loose boulders. Boulders and weathered blocks of stones are not fit for important constructions. The term *quarry* refers to the places exposed to air like a stone outcrop from which we extract the building stones. On the other hand, the term *mine* refers to the places where we extract mineral resources like coal, precious stones, etc.

1.4.1 Quarrying Methods

The method used for quarrying of stones depends on the type of stone, its intended use and the type of its geological formation. For example, when the rock formation consists of horizontal layers at shallow depth, we may be able to easily quarry them in layers. On the other hand, if the stone is one whole crystalline mass, we may have to blast them with explosives. Similarly, the method to be used for regular building blocks will be different from that used to produce stone ballast. We can classify methods of quarrying into the following three groups.

1. Quarrying with hand tools
2. Quarrying by use of channelling machines and
3. Quarrying by blasting with explosives.

We will deal with each of them briefly.

Quarrying with hand tools

These are the old methods and are still used for soft stones occurring in large or small blocks. They give well-shaped blocks for construction of masonry. The following are the methods used:

(a) *Digging and excavating.* This is applicable for soft stones occurring in small blocks. Primitive instruments like pick axes, shovels, chisels are used in this method. Laterite is mined easily by this method.

(b) *Heating.* If the rock occurs in layers and if the surface is heated by fire, the differential expansion separates the upper layer from the lower layer.

(c) *Wedging.* If the rocks contain cracks and fissures, steel wedges are driven through the cracks and the pieces are separated. If natural cracks are absent, holes of about 10 cm diameter and manageable depths (20 to 25 cm) are first made along a line at 10 to 15 cm distance either by hand tools or pneumatic drills. Flat steel wedges, with its upper end curved outwards known as *feathers*, are inserted into the holes on either side. Between these feathers, conical steel plugs are driven. When these plugs are driven in the rocks drilled along a line, cracks are formed along these lines in the rock and at the depth of the holes. These blocks thus separated are lifted up. (Instead of wedging, we can use controlled small explosives to separate the blocks from the mass). Wedging works very well in soft rocks like marble, limestone, sandstone, etc.

Quarrying by use of channelling machine

For using quarrying machine, one of the faces of the solid rock to be quarried should have an exposed face. In this process, we use a channelling machine driven by steam, compressed air or electricity. This machine can cut 50 to 75 mm width channels up to 24 m in length and 240 to 370 cm in depth. The process consists of the following steps:

(a) We first cut channels of sufficient depth with the channel machine along the three sides which form the plan of the block to be removed.
(b) Horizontal holes are then driven beneath the block from the exposed face.
(c) Wedges are then driven into the horizontal holes when the block will break loose.
(d) The block is lifted from its bed to be cut into the slabs of required sizes.

Blocks of granite and other rocks for cutting into slabs and polishing for floor slabs or facing work as well as large blocks of stones that are exported for the above purposes are mined by this method.

Quarrying by blasting

This method is most commonly used for manufacturing of stone aggregates or ballast for railways. This method usually breaks up the block into irregular blocks and pieces which can be later crushed to give coarse or fine aggregates. The method does not produce regular sized stones for masonry, but the product can be used for irregular work like random rubble masonry. As all civil engineers should know the elements of rock blasting a brief account of the procedure is given below.

Materials used for blasting. Explosives used for blasting can be gunpowder, (a mixture of charcoal, saltpetre and sulphur) or other manufactured chemical explosives like dynamite available from government-controlled agencies. (We should be aware that stocking explosives without licence is a crime.)

When we use gunpowder for blasting, we use a *cotton fuse wire* which ignites the explosives. It has the form of a rope of cotton coated with tar with a core of continuous thread of gunpowder. The average rate of burning is only about one cm per second (slow match fuse) which helps the person firing it to move safely away from the explosion. Gunpowder blasting is not possible in damp environment and under water.

For firing chemical explosives like dynamite, we generally use a *detonator*. A detonator is a device with a copper cylinder (about 6 mm diameter and 25 mm in length) closed at one end and projecting fuse at the other. It contains 6 to 9 g of fulminate of mercury (derived from fulminic acid) which can be fired by an ordinary fuse or an electric spark. The small explosion of the detonator starts the large explosion of the dynamite. The advantage of using a detonator with an electric circuit device for firing is that the time of commencement of the explosion can be controlled well. Such control is necessary when we have to control the time, order and magnitude of the explosion for the maximum benefit. (For demolition works of tall towers and construction of tunnels, such controlled firing is necessary.)

The various chemical products used for blasting are given in Table 1.2. As already pointed out, in general, blasting with gunpowder produces large blocks whereas the shattering power of dynamite produces small blocks of stones. Hence, the latter is generally used for quarrying for aggregates and for works like tunnelling and mining. Using dynamite is about 4 to 5 times costlier than using gunpowder for quarrying.

Table 1.2 Major Nitroglycerine Explosives used for Blasting

S.No.	Name	Composition and use
1.	Dynamite	75% nitroglycerine where high explosive powder is needed
2.	Gelatine	Jelly-like mass consisting 93% nitroglycerine and 7% guncotton, it is 50% more powerful than dynamite
3.	Cordite	Gelatinized combination of nitroglycerine and nitrocellulose
4.	Gelignite	65% gelatine and 35% absorbing powder

Note: Other substances like guncotton, liquid oxygen and rock-a-rock are also used as explosives. They are less popular than nitroglycerine products.

Blasting procedure. The various steps followed in blasting with gunpowder or other explosives are the following. (Figure 1.1).

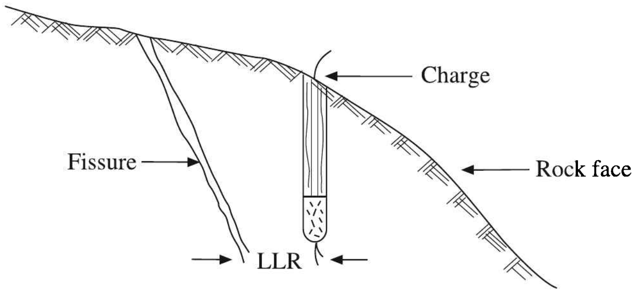


Figure 1.1 Rock blasting.

1. The blast holes of required diameter and depth are made along the lines at the required spacing, so that the required size of block can be produced. The holes are cleaned and dried well using a piece of dry cloth.
2. The necessary quantity of gunpowder or explosive is placed at the bottom of the hole keeping the top part of the hole free. The quantity will depend on the spacing of the holes and the line of the least resistance (L.L.R) of the rock, which is the shortest distance between the centre of the charge and the rock's nearest free surface as shown in Figure 1.1.
3. After placing a greased thin copper needle (priming needle) at the centre of the hole, the top part of the hole is filled with layers of sandy clay, moorum or anthill earth in layers, with each layer well rammed in place with a brass tamping bar. This forms a hole for the fuse to be placed.
4. The priming needle is then withdrawn, and a fuse wire of sufficient length is cut at one end and inserted through the hole, into the gunpowder. The other end of the fuse wire is kept projecting out by about 60 to 90 cm. (On the other hand, when we use dynamite as explosive, we usually use a detonator. One end of the fuse wire is connected to the detonator which is lowered into the hole. The other end of the fuse is kept above the hole as in the case of gunpowder firing.)
5. The free end of the fuse is fired either directly by a fire or by use of electric spark. (Firing by electricity has many advantages like better control and ability to use in wet places.)

1.5 CRITERIA FOR SELECTION OF STONES

Stones should be selected according to their use. In any case, it should be durable and free from defects.

1. ***Stone for masonry.*** Any type of stone can be used for rough work like random rubble. However, for ornamental works and dressing the stones to different finishes (as for ashlar work), we have to use stones suitable for these purposes. Soft stones like limestones and sandstones can be dressed more easily than granite. For ornamental works in temples

or heavy engineering works like facing work in docks and harbours or bridge piers, we will prefer well-dressed granite.

2. ***Stone for pavements.*** Generally, hardstones of any type can be used for paving walkways, driveways, etc.
3. ***Stone for flooring.*** Stones are used for heavy duty flooring in many situations. Nowadays, with the help of machines, we can produce large slabs for flooring even from hard rocks like granite. In some locations like bathrooms, marble floorings are prefered. Materials like marble, kotastones can take polish and are prefered in many places. They can also be obtained in pleasing colours. Cuddapa slabs are popular for using in kitchen platforms, shelves, etc.
4. ***Stones for facing work in buildings.*** The facing stones should have attractive colours. It should be durable. Both impervious stones like granites, marbles and pervious stones like limestones are used. The impervious varieties are preferred as they do not get change in colour with time, especially in an industrial atmosphere.
5. ***Stones for concrete aggregates.*** Hard igneous rocks like granite are always prefered for high strength concrete as needed in prestressed concrete. Aggregates of moderate strength like limestones are also useful for making concrete of moderate strength.

1.5.1 Characteristics to be Considered in Selection of Stones

The desirable qualities depend on the use of the stone. Hard stones are used for heavy engineering works like building quay walls. Many types of stones are used as aggregates for concrete. Stones like marbles are used for appearance. Now, we will deal with the important general properties to took for.

1. ***Crushing strength.*** The following are the ultimate strengths of some of the common types of stones as compared to 15 to 20 N/mm^2 for ordinary concrete.

   (a) *Igneous rocks*
   Granite 80 to 150 N/mm^2
   Basalt 150 to 200 N/mm^2
   Trap 300 to 350 N/mm^2

   (b) *Metamorphic rocks*
   Gneiss 200 to 350 N/mm^2
   Slate 75 to 200 N/mm^2

   (c) *Sedimentary rocks*
   Limestone 50 to 60 N/mm^2
   Sandstone 50 to 70 N/mm^2
   Shale 1 to 10 N/mm^2

   (d) *Other types*
   Laterite 2 to 3 N/mm^2

   Most of the stones have more than the required compressive strength for masonry, compared to hand-made bricks available in India with a strength of only 2 to 10 N/mm^2.

2. ***Appearance.*** Appearance is very important for stones used for decorative works and the facing work of buildings.
3. ***Density.*** It should be dense. Its specific gravity should be greater than 2.7.
4. ***Durability.*** This property is very important, especially when used in exposed conditions.
5. ***Easiness of dressing.*** This property depends on its usage. Stones used for facing work should have easiness to get dressed to the required texture.
6. ***Fire resistance.*** Argillaceous stones like limestones resist fire better than the stones containing quartz which explodes on heating. Thus, limestone resists fire up to 800°C whereas granites with quartz minerals can stand only up to 600°C.
7. ***Fracture.*** The grains should be well cemented and sharp if we examine a fractured surface.
8. ***Impact resistance.*** It is a measure of toughness of the stone. An impact test value of 19 is good and a value below 13 shows bad quality of stone. (See Section 8.5.7)
9. ***Hardness.*** This test gives resistance against wear as in road works. Hardness greater than 17 is good and less than 14 is considered as poor. (See Section 1.11, item 10)
10. ***Resistance to wear.*** Resistance to wear is indicated by attrition test. (See Section 8.5, item 8) It is also an important quality for use as coarse aggregate in concrete. For a good facing stone, its value can be as low as 3. However, for use as coarse aggregate a much higher value is needed.
11. ***Seasoning.*** Many type of stones fresh from the quarry contain moisture (quarry sap). They can be dressed easily at freshly quarried stage. Such stones should be dressed and kept apart for some time for the moisture to evaporate before they are used. (For example, laterite is a special stone which require good seasoning. When quarried, it is soft, and it hardens only when exposed to the atmosphere. The iron compounds get oxidized and gives it the necessary strength. Hence, laterite should always be dressed as soon as it is quarried and stored away from rain for some time before it is used on the works.)
12. ***Texture.*** It should have a pleasing texture and should be free from cracks and cavities.
13. ***Water absorption.*** For durability the percentage of absorption should be less than 0.6 per cent. Otherwise, in exposed situations, water can seep into the stone and leach out the salts.
14. ***Weathering.*** It should weather well as shown by its use in similar types of old buildings in which they have weathered well.

1.6 DETERIORATION OF STONES

The following are the main causes for deterioration of stones:

1. Alternate wetting and drying.
2. Alternate freezing and thawing.
3. Deleterious substances present in the air such as in the atmosphere near the seashores and industrial areas.

4. Living organisms, growth of vegetation (like seedlings of banyan trees that grow from droppings of birds) and living worms or bacteria that live in the stone can cause decay.
5. *Movement of chemicals between materials.* This occurs when limestones and sandstones are used together. The granular limestone can absorb magnisium sulphate present in other rocks if they are used adjacent to the other.
6. *Nature of mortar.* If the mortar has chemicals, they can affect the stonework.
7. *Temperature variation.* Large variations of temperature and alternate heating and cooling can cause expansion and contraction which cause cracking of stone.
8. *Waterfalls and rainfalls.* Falling of water from great heights or falling of water containing chemicals (like rainwater absorbing gases from the atmosphere) can cause deterioration of stones.
9. *Wind.* Winds blowing for a long time can over deserts contain sand and dust, which passing over the stones for a long lime can cause their deterioration.

1.7 PRESERVATION OF STONES

There are two aspects to be considered under this heading. Firstly, the precautions to be taken before and during the construction of stonework and secondly, the steps to be taken after the stonework has been completed.

1.7.1 Precautions During Construction

The precautions to be taken during the construction are the following:

The type and size of stones selected should be good. Only compact and durable stones should be selected for construction. The size of these stones should be as large as possible to minimize the number of joints. The stones should be well seasoned and washed clean before they are used. The construction should be up to the required specifications. The stones should be placed on their natural beds and the joints completely filled with mortar so that there is no cavity. *External renderings like pointing is preferred for exposed stones.* Otherwise, it should be plastered with high-quality plaster.

1.7.2 Methods of Preservation of Completed Stonework

Stonework after construction also needs careful attention if they are to be preserved in their natural condition. The art of preserving ancient stone statues in museums consists of special techniques and is a specialised subject. For *preserving stonework in buildings* which tend to deteriorate with time, we usually resort to coating the stone with one of the following preservatives.

1. ***Linseed oil.*** Raw linseed oil is light in colour while boiled linseed oil is dark and hence discolour the stone.
2. ***Solution of alum and soap.*** Alum and soap in 40 to 60 proportions respectively dissolved in water can be applied on the stone to act as a protective coating.
3. ***Solution of barium hydroxide* (Baryta).** If the decay is due to $CaSO_4$, then this treatment is effective. The reaction is as follows

$$Ba(OH)_2 + CaSO_4 = BaSO_4 + Ca(OH)_2$$

The barium sulphate is insoluble and the $Ca(OH)_2$ absorbs carbon dioxide and gives strength to the stonework.

4. ***Paraffin.*** It is used alone or dissolved in naphtha as a paint medium. However it may changes the colour of the stone.
5. ***Paint.*** Painting preserves the stone but changes the colour of the stone. If applied under pressure, it can fill the pores in the stone. The paint should be neutral and should not react with the stone. Modern colourless paints are also available.
6. ***Coal tar.*** Even though it is listed as a preservative, it is a highly objectionable material to be used as it completely changes the colour of the stone. The chemicals in coal tar may not also suit some types of stones.

1.7.3 Conservation of Granite

As there are a large number of art works and monuments made of granite in this world, a large amount of research has gone into methods of conservation of granite. In general the following three methods are commonly used depending on the state of existence of the granite work to be made good:

1. Consolidation using consolidants
2. Injection using injection materials and
3. Filling using filling materials.

The binding medium used are ethylsilicate, acrylic resin, epoxy resins and others. Filler materials like suitably coloured sands from 0.1 mm to 2 mm are also added if needed. This art of conservation of stones and especially granite is extensiverly practiced in the laborations attached to museums.

1.8 ARTIFICIAL STONES

Artificial stones are materials like terrazzo and mosaic. Cement concrete also come under this class. Concrete flooring is sometimes called patent stoneflooring. Special artificial stones resembling large stone blocks can also be prepared by casting smaller stones or stone chips with pigmented cement in specially constructed moulds and polishing them as required. The following are the advantages of artificial stones:

1. They can be cast as per the architectural requirements. Stones of any shapes and sizes or features like grooves, can be obtained easily.
2. They can be made economical. Large concrete blocks are more economical than natural stone blocks.
3. As natural bed is absent, placing them is more convenient than the natural stones and needs less supervision. Natural stones should be placed with their bed in compression.
4. No defect or cavity will be present as compared to natural stones. Hence, they are more durable.
5. They can be made even in places where deposits of natural stones are not available as broken stones can be easily transported.

1.9 STONE VENEERING

Stone is used in many important buildings for facing work. Wall faces are covered with thin polished tiles or slabs cut from selected stones like sandstones, marble, coloured granite, etc. Such work is called stone veneering work. They provide a decorative and maintenance-free finish. IS 4101-1967-Part 1 cover specifications for stonefacing works. Stone units cut by machines are again cut to smaller pieces by powerful machines. They are also polished to suit the facing work. A large number of factories making these products have been established in many cities in India. Large blocks of stones are exported from India, for conversion into veneers, to foreign countries like U.S.A. and Japan.

1.10 TEXTURAL CLASSIFICATION OF ROCKS

The textural classification of rocks also gives an indication of their strength. The basis of such classification is as follows:

1. ***Textural classification of igneous rocks.*** It is based on *mineralogy and mode of occurrence*. Both the mineral content and the grain size tend to be an indication of the rate of cooling. These various rock-forming minerals can be grouped into feldspars, silica minerals, mica, etc. The modes of occurrence are as follows:
   (i) Volcanic or extrusive-like basalt
   (ii) Plutonic (cooled below the depth) like granite
   (iii) Minor intrusive-like (formed as dykes and sills, etc.) dolerite
2. ***Textural classification of sedimentary rocks.*** It is based on the formation of the rocks—whether they are mechanical sediments like sandstone and quartzite or chemical *precipitants* like limestone and dolomite. The further textural classification of the *sedimentary rocks* are the following:
   (i) Clastier (composed of previously existing solid matter) and also called granular-like sandstone
   (ii) Crystalline like limestone and dolomite
   (iii) Biotragmental (of biological origin) like coal and limestone
3. ***Textural classification of metamorphic rock.*** It is based on its grouping into the following three groups.
   (i) Granular–like marble
   (ii) Branded–like gneiss with platy and elongated grains
   (iii) Foliated (shaped like leaves) as in schist slate, etc.

When we identify a rock in foundation investigation, we try to describe its structure as one of discussed in this section in our description of the rock.

1.11 PHYSICAL TESTS ON STONES

Building stones are to be tested for the following tests:

1. Absorption test
2. Smith's test

3. Toughness test
4. Moh's scale of hardness test
5. Acid test
6. Crystallization test
7. Attrition test (see also Chapter 8 on coarse aggregates)
8. Crushing test
9. Freezing and thawing test (for cold countries)
10. Hardness test (see Chapter 8 on coarse aggregates)
11. Impact test (see Chapter 8 on coarse aggregates)
12. Microscopic test

Tests 1 to 6 are simple tests that can be carried out in the field and are usually made on building stones. Tests 7 to 12 are carried out in a laboratory and are often performed to find suitability of coarse aggregate for concrete. These tests are briefly described below:

1.11.1 Simple Field Tests

1. ***Absorption test.*** This is a simple test that should be done on all stones. It consists of keeping a sample of rock of about 50 gm in distilled water and finding the water absorbed in 24 hours. It should not exceed 0.6 per cent.
2. ***Smith's test.*** This test is to determine the deterioration of stones when immersed in water. A sample of the stone is placed in distilled water in a glass vessel and vigorously stirred. It is kept in water for at least 24 hours. If the water turns muddy, then the stone contains earthy substances. Some very consolidated sands which look like sandstones simply slump under water in this test. We should ensure that all stones we use pass this test.
3. ***Toughness test.*** Hit the stone with a hammer and find how tough it is to break it with the hammer.
4. ***Moh's scale of hardness test.*** One simple way of describing strength of stones is in terms of hardness of the surface. We scratch the stone with a penknife and classify hardness by Moh's scale of hardness. It is based on the relative abrasiveness of minerals (the softest being talc and the hardest diamond), the scale being divided into 10 scales as shown below:
   1. Talc
   2. Gypsum
   3. Calcite
   4. Fluorspar
   5. Apatite
   6. Orthoclase feldspar
   7. Quartz
   8. Topaz
   9. Corundum (Saphire)
   10. Diamond

(*Note:* Schmidt rebound hammer tests are increasingly being used for finding the strength of in situ rocks than Mohr's hardness test.)

5. ***Acid test.*** This is to test the presence of poorly weathering calcium carbonates in sandstones. The test consists of placing a cube of the stone weighing about 50 to 100 gm in one per cent hydrochloric acid for 7 days. A good building stone should be free from powder formation on the surface of the cube and the sharp edges should not be broken up after the above immersion.
6. ***Crystallization test.*** This test consists in immersing a sample of stone (cubes of say 40 mm) in 14 per cent sodium sulphate solution for two hours and then drying it in an oven at 100°C. This procedure is repeated for at least five times. The loss of weight and the presence of cracking are noted. There should not be any visible defect formed, and the loss in weight should be minimal.

1.11.2 Laboratory Tests

1. ***Attrition test*** (as described under coarse aggregates). This is carried out in a *Deval testing machine* (see Chapter 8, Section 8.5.8).
2. ***Crushing test.*** This test consists of finding the compressive strength of a stone cube 40 mm in size in a compression-testing machine. The rate of loading used is 140 kg per cm^2 per minute.
3. ***Freezing and thawing test.*** This test is applicable to the regions where the temperature can go below the freezing point. It consists of keeping a specimen of the stone in water for 24 hours and then freezing it at –12°C for 24 hours. It is then thawed. This is repeated at least seven times after which the specimens are carefully examined for any damage.
4. ***Hardness test.*** This test is different from the attrition test. Here, we use the *Dorry's testing machine*. A cylinder of 25 mm of the rock is rubbed against a steel disc sprinkled with coarse sand. The specimen is given a pressure of 1.25 kg. After 1000 revolutions, the loss in weight is determined.

$$\text{Coefficient of hardness} = \frac{20 - \text{Loss of weight (g)}}{3}$$

5. ***Impact test*** (as described under coarse aggregates in Section 8.5.7).
6. ***Microscopic test.*** In this test, thin sections of the stone are taken and placed under the microscope to study its grain size, mineral constituents and presence of harmful materials.

SUMMARY

Stone is an important material for building construction. By simple field tests and if necessary, laboratory tests, we can identify the suitability of a stone for building construction. For ornamental work and facing works, special attention should be given to its appearance and capacity to take polish. For use as aggregates, they can be easily tested for its suitability.

Review Questions

1. What are the geological, physical and chemical classifications of rock?
2. Name five construction works where you would use stonework? State also what stones would you recommend for these works?
3. Enumerate the characteristics to be considered for selection of stones for various civil engineering works.
4. Describe the methods of quarrying stones (a) for veneering work and (b) for producing coarse aggregate for concrete. How do you mine laterite?
5. What are the simple field tests that you can carry out to determine the suitability of stone to determine quality of stones?
6. Briefly explain the laboratory tests that are usually carried out to determine the quality of stones.
7. What are the factors that produce deterioration of stones. How can granite stoneworks be preserved?
8. Write short notes on:
   (a) Quarry and mine
   (b) Laterite stones
   (c) Cuddappa slabs
   (d) Kota stones
   (e) Marble
   (f) Artificial stones
   (g) Stone veneering
   (h) Stone floorings
   (i) Scale of hardness of stones
9. Write short notes on:
   (a) Smith's test
   (b) Absorption test
   (c) Crystalization test
   (d) Acid test.

References

[1] IS 1121–1974 (Parts 1 to 3): Methods of Test for Determination of Strength and Properties of Natural Building Stones (Part 1, Compressive strength; Part 2, Transverse strength; Part 3, Tensile strength).

[2] IS 1123–1975: *Method of Identification of Natural Building Stones.*

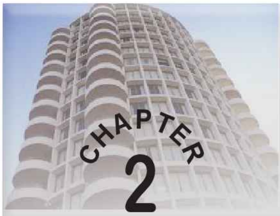
[3] IS 1124–1998: *Method of Test for Determination of Absorption, Apparent Specific Gravity and Porosity of Natural Building Stones.*

[4] IS 3620–1998: *Specification for Laterite Stone Block for Masonry.*

[5] IS 3622–1998: *Specification for Sandstones (Slabs and Tiles).*

[6] IS 4081–1986: *Safety Code for Blasting and Related Drilling Operations.*

[7] IS 4101–1967: *Code of Practice for External Facing and Veneers* Part 1, *Stone Facing;* Part 2, *Cement Concrete Facing;* and Part 3, *Wall Tiling* and Mosaics.



CHAPTER 2

Clay Bricks

2.1 GENERAL

Clay bricks were used by humans from very early dates. First it was used without burning as sundried bricks. Burnt brick was a common building material among the Egyptians. Nowadays, they are made from specially selected and matured brick-earth consisting chiefly of silica (35 to 70 per cent) and alumina (10 to 20 per cent). Too much silica tends to make the brick brittle and too much alumina makes the brick warp and crack on drying and burning. It is also desirable to have other agents like lime, magnesia, oxide of iron which act as colouring agent and flux to assist fusion during burning of the brick earth. If they are not naturally present, they should be added to the clay during mixing. Clay when heated to lower temperatues, loses its moisture, and only *physical change* occurs. Such half-burnt clay crumbles when placed in water. However, when clay is heated to high temperatures, its constituents fuse, and *chemical change* takes place. Such well-burnt bricks do not breakdown when immersed in water. The temperatures in these kilns go 700 to 1100°C. In this chapter, we will deal with the manufacturing of clay bricks and methods of testing them for use in building construction.

2.2 BRICKCLAY

A brick earth quarry should contain clay which is suitable for brickmaking or which can be made suitable by mixing with other soils. Laboratory tests like liquid limit, plastic limit and shrinkage limit may also be used to determine the suitability of the soil for brickmaking. Alternately, the suitability may be judged by an experienced person by the feel on kneading it between the fingers. We should remember that requirements of *clay for making tiles are different from those of bricks*, the former requiring more plastic clay than the latter as they are to be moulded into thinner impervious sections as compared to bricks (see Section 27.11).

2.3 PREPARATION OF BRICKS

The following are the various steps for the preparation of common bricks.

1. ***Preparation of clay.*** After removal of vegetation, the clay deposit is excavated in steps rather than in layers to ensure a better distribution of the several constituents which vary in different proportions at different depths. Further processing of the clay depends

on the type of bricks to be made. For ordinary country bricks, very little preparation except mixing by treading is resorted to. For making first class facing bricks, the clay is allowed to weather by keeping it exposed to open air for a considerable period so that the lumps of clay break down into smaller particles and get *matured*. As a further refinement for making very superior bricks, the clay is washed and processed before moulding into bricks. For making clay tiles also we use the clay that has been processed.

2. ***Moulding of bricks.*** Bricks are moulded in many ways depending on the quality of the product to be made. They may be hand-moulded or machine-moulded (as wire-cut bricks) or pressed by machine or in moulds.
3. ***Burning of bricks.*** Burning of bricks is carried out in temporary *clamps* or in permanent *kilns*. In *clamps,* one batch of green bricks is heaped along with firewood, coal, etc. and sealed with clay. It is then fired slowly to intense heat which may take many days. Modern *kilns* are, however, permanent structures consisting of many chambers. There are intermittent and continuous kilns. Moulded clay is stacked in the chambers. They are then slowly dried and burned to high temperature and cooled. One cycle of loading, drying, burning, cooling and emptying may take as much as two weeks. These processes are carried out intermittently in intermittent kilns and in cyclic order in continuous kilns. Nowadays, kilns have almost superseded clamps as the heat can be controlled better in kilns, and the bricks produced in them are of more uniform quality than those produced in clamps. Also, there is saving in the cost of the fuel.

2.3.1 Types of Bricks Made

Bricks are moulded either by hand (by manual labour) or by machine. In India, the *hand-moulded bricks* are more common and less costly than the machine-moulded bricks. They can be ground-moulded or table-moulded. The latter process is carried out with more care and produces better brickes as compared to the farmer one.

Wire-cut bricks are made by machine as follows: The prepared clay is fed into a pug mill from which it is forced through a mouthpiece approximately equal to the cross section of the brick as a continuous band. This is conveyed by rollers to a frame which contains several fine vertical wires of approximately the height of the brick. These wires cut the clayband into brick sizes which are then fired. Hence, they are called wire-cut bricks.

Pressed bricks are made by putting the wire-cut slab into a mould and further pressing it with a metal plate above the clay block, thus consolidating it. Pressed bricks are, thus, superior to wire-cut bricks and are used for facing or other decorative works.

In general, we get four types of bricks in the market. They are as follows.

1. *Ground-moulded bricks usually fired in temporary clamps.* The dimensions of these bricks are not regular.
2. *Table-moulded bricks fired in kilns.* These bricks are also called stock bricks.
3. *Machine-moulded bricks fired in continuous kilns.* These bricks are also called wire-cut bricks.
4. *Pressed bricks made under pressure.* These bricks are used for decorative works.

2.4 CHEMICAL CHANGES IN BURNING OF BRICKS

It is very important to understand what happens to clay when it is burnt. Heating clay up to about 640°C produces only *physical changes*. The moisture is driven out, the organic matter is burnt out and water of crystallization is driven out. If such clay is cooled back, it absorbs moisture from the air and gets hydrated back more or less to its original state. If such a block is immersed in water, it disintegrates. Such poorly-burnt clay is unstable.

However, if we heat clay up to 700 to 1000°C *chemical changes* take place by which alumina and silica in the clay fuse together resulting in a compound which is strong and stable. It is different from the original clay and after this chemical transformation, it does not turn back to clay on cooling. It also does not crumble down like clay when immersed in water. It is a product different from the original clay. Thus, proper burning to the required temperature is a necessity in brickmaking.

If we heat the clay beyond 1300°C, the above materials get vitrified. The bricks begin to lose their shape. Tiles heated to high temperatures are called vitrified tiles. Vitrified tiles are nowadays extensively used as floor tiles (see Chapter 31).

2.5 DIMENSIONS OF BRICKS

Bricks are made in traditional size and also in metric size prescribed by Bureau of Indian Standards. The bricks of latter sizes are also called *modular bricks*. Depression made at the top of a brick is called the *frog*. Brickwork is constructed with the frog laid facing upwards. It serves to place the name of the manufacturer and also as a key to the mortar to bond bricks together. The prescribed actual and nominal dimension as per I.S. is given in Table 2.1.

Table 2.1 Prescribed (Actual) Sizes of Bricks
(Ref. C.P.W.D. Specification 77, Vol. I)

Size	Ordinary bricks		Tile bricks	
	* Metric (cm)	F.P.S. (inch)	* Metric (cm)	F.P.S. (inch)
Actual	19 × 9 × 9	$8\frac{7}{8}\times4\frac{3}{8}\times2\frac{3}{4}$	19 × 9 × 4	$8\frac{7}{8}\times4\frac{3}{8}\times1\frac{3}{4}$
Nominal	20 × 10 × 10	$9\times4\frac{1}{2}\times3$	20 × 10 × 4	$9\times4\frac{1}{2}\times1\frac{3}{4}$

Notes:

(i) ***Nominal size of bricks is the size including*** **the thickness of the mortar. The thickness of the mortar in brickwork should not exceed 10 mm (3/8″).** Generally, horizontal joints will be thicker than vertical joints. Thus F.P.S. bricks are sized as $9''\times4\frac{1}{2}''\times3''$ (nominal). Tile bricks are used for paving roofs.

(ii) Bricks of thickness lesser than normal are called tile bricks.

(iii) Metric bricks are also known as modular bricks. They conform to the standards specified by B.I.S. as shown above.

(iv) We need approximately 500 metric bricks for one cubic metre of brickwork (or 1350 bricks for 100 cubic feet of brickwork), not including wastage.

2.6 WEIGHT OF BRICKWORK

It is necessary to know the deadweight of brickwork in design of buildings. It is generally taken as 18 to 19 kN/m^3. The average weight of a brick is about 3 to 3.5 kg depending on its denseness. The deadweight of a 225 mm (9 inch) thick wall can be taken as 4.1 to 4.4 kN/m per metre height. Lightweight hollow bricks can be as low in weight as only one-third the weight of a common brick, (see Section 2.10). Similarly, hollow concrete blocks can also be used to reduce the deadweight of masonry in buildings.

2.7 STORING OF BRICKS

Bricks are not generally stored for long periods as they are usually used up in construction as soon as they are delivered at the site. Each truckload should be piled in separate stacks on the ground, at not more than the height convenient for a person to reach them for removing them. If the bricks are weak and liable to be damaged by rains, then they should be stored in covered sheds during the rainy season.

2.8 BRICKS FOR SPECIAL USE

As already stated, bricks may also be made for special purposes such as the following.

1. ***Facing bricks.*** These bricks are generally made from selected clay (which will give the necessary colour on burning or with special colouring agents added) and by pressing it in special moulds.
2. ***Fireclay bricks.*** These special bricks are made for lining in devices such as furnaces, digesters, ovens and so on. They are also called *refractory bricks*. They are made from special clays called fireclay. Fireclay bricks are used for lining in chimneys, furnaces and other situations exposed to very high temperature. These bricks should also be laid with fireclay mortar and not with cement mortar, when built as lining for chimneys. They are available as acidic, basic and neutral bricks.
3. **Acid-resisting bricks.** These bricks are special bricks manufactured from materials of low clay content and fired at temperatures sufficiently high to convert the constituents largely into crystalline minerals which are insoluble in acids and alkalis.
4. ***Forsterite bricks.*** These bricks are made from olivine rock to which magnesia is added in the manufacturing process. The chief constituent is the mineral forsterite (2 MgO, SiO_2). They are very stable at high temperatures. They are used in open hearth furnaces and refining furnaces.
5. ***Silicon carbide bricks.*** These bricks are made of carbon and silicon. They are used in the electric resistance furnace. It is inert to all acids and is used as a refractory material.

2.9 CONVENTIONAL AND SPECIALLY SHAPED BRICKS

The usual types of bricks made are shown in Figure 2.1. Many specially shaped bricks like single bullnose, double bullnose and curved bricks are also made for special purposes in building construction.

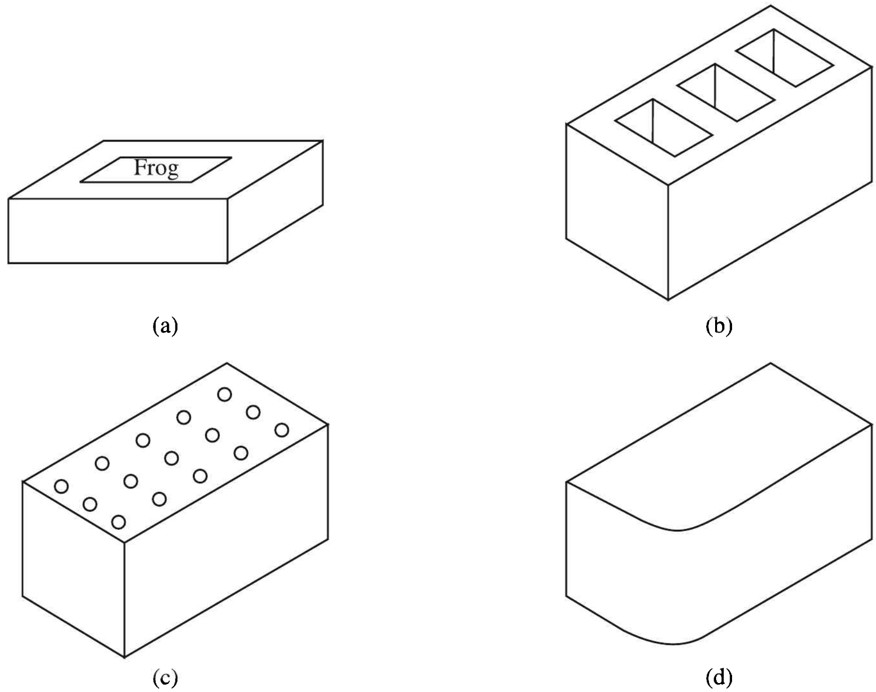


Figure 2.1 Types of bricks (a) Common brick with frog (b) Hollow brick (c) Perforated brick (d) Bullnose brick.

2.10 LIGHT-WEIGHT CLAY BRICKS

In many situations, such as the following, we may require light-weight clay bricks to reduce the deadload.

1. In tall buildings, to reduce the deadweight of walls and thus, reduce the load on the foundation.
2. In partition walls, to reduce weight and insulate them from sound.
3. In walls above cantilever beams to reduce the weight.

Light-weight bricks can be made using one of the following methods:

(a) As solid bricks made from clay mixed with combustible materials which burn off during leaving a porous, light brick the fire.

(b) As hollow bricks in which the brick contains hollows with ribs. They are usually made from tile clay as the ribs have to be thin and strong. They are available in many sizes (to suit outer and partition walls) including bricks of standard sizes. The weight of these hollow bricks can be as little as one-third the weight of the corresponding solid bricks.

2.11 BRICK SUBSTITUTES

As bricks are made from clay excavated from the earth, availability of good brickearth is becoming less and less whereas the demand for bricks for construction is increasing. Hence, it is necessary to produce bricks from industrial wastes and other raw materials. The presently available such bricks are the following.

(i) Flyash bricks
(ii) Sandlime bricks or calcium silicate bricks
(iii) Cement and concrete blocks (see Chapter 3).

Flyash bricks are made from the flyash which is obtained as a waste material from burning of coal or lignite in various industries, especially in power houses. Lime or cement is also added to give the bricks required strength. Many factories are now coming up in India to manufacture flyash bricks. The Indian government also eneourages this use of the waste product by giving concessions in its manufacture.

Silicate bricks are made by autoclaving sandlime bricks (made from sand, lime and water with added pigments for colour) with high pressure steam in special chambers. They are yet to become popular in India because of their high energy cost.

2.12 CLASSIFICATION OF BRICKS

Bricks can be classified in three ways namely according to their use, or its general physical requirements and strength or as in IS classification. The classification of bricks on the basis of these criteria is as follows:

(a) ***According to use.*** Bricks are, sometimes, broadly classified according to their uses as:

(i) Common bricks
(ii) Engineering bricks (special bricks for carrying heavy loads)
(iii) Facing bricks
(iv) Fire bricks
(v) Specials (special shapes)

(b) ***According to general physical requirements.*** In some specifications, claybricks are classified as Class I, Class II and Class III according to their general physical properties indicated in Table 2.2. As can be seen, the bricks of different classes differ in their water absorption property. No good brick should disintegrate when immersed in water even for a long period. Such disintegration shows lack of good burning.

(c) ***I.S. Classification of bricks.*** Indian Standards I.S. 3102–1971 "Classification of burnt clay solid bricks" classify bricks according to their strengths as given in Table 2.3.

Table 2.2 Requirements of Different Classes of Burnt Clay Bricks

	Class I Bricks	Class Ii Bricks	Class Iii Bricks
1. General requirements	Shall have a uniform colour, shall be thoroughly burnt but not overburnt, shall have plane rectangular faces with parallel sides and sharp straight right angled edges. They shall have a compact and uniform texture.	Shall have a uniform colour and may be slightly overburnt. The bricks may be slightly distorted and have round edges. They shall have a fine compact and uniform texture.	May be slightly underburnt or overburnt. They may be distorted and have round edges. The defects in uniformity or shape shall not be such as to cause difficulty in obtaining uniform courses with their use.
2. Water absorption after 24-hour immersion in cold water.	Not more than 20 per cent by weight.	Not more than 22 per cent by weight.	Not more than 25 per cent by weight.
3. Efflorescence	Slight	Slight	Moderate

(*Note:* Coverburnt bricks are classified as fourth class bricks.)

Table 2.3 I.S. Classification of Bricks According to Strength

Class designation	Compressive strength requirement (not less than)	Additional requirements
10	10 N/mm^2	Dimensional tolerance ±3%, surface must be smooth, corners should be sharp, should give a ringing sound when struck.
7.5	7.5 N/mm^2	Dimensional tolerance ±8%, permitted to have slight distortion but it should not cause difficulty in laying.
5.0	5.0 N/mm^2	Dimensional tolerance ±8%, permitted to have slight distortion but it should not cause difficulty in laying.
3.5	3.5 N/mm^2	Dimensional tolerance ±8%, permitted to have slight distortion but it should not cause difficulty in laying.

Note: Generally, factory-made (wire-cut) bricks in India give a strength of the order of 17 N/mm^2 when dry and 12 N/mm^2 when wet. Common hand-made bricks, generally, give the strength of the order of only 3 to 5 N/mm^2 when dry.

2.13 SAMPLING FOR TESTING OF BRICKS

Indian Standards I.S. 3495–1992 "Method of test for burnt claybricks parts 1 to 4" gives details of the tests. The sampling and testing of bricks is carried out as shown in Table 2.4.

Table 2.4 Sampling and Testing of Bricks (I.S.)

Class designation	Sampling size	Lot size	Tests to be made
10	20 bricks	50,000 or more	1. Comp. strength
			2. Water absorption
			3. Efflorescence
			4. Dimensional test
			5. Hardness
			6. Soundness
7.5 to 3.5	20 bricks	100,00 or more	Tests at the discretion of the Engineer in-charge

2.13.1 Tests for Bricks

The tests to be made on bricks, as already given in Table 2.4 are as follows:

1. Compressive strength
2. Water absorption
3. Efflorescence
4. Dimensional tolerance
5. Hardness
6. Soundness.
7. Structure

We will now deal with the above-mentioned tests.

1. ***Compressive strength.*** Five bricks are taken at random and their dimensions are measured to 1 mm accuracy. They are, then, immersed in water of 25°C to 29°C for 24 hours. The surplus moisture is allowed to drain and the frog, if any, is filled with mortar 1:3 (1 cement, 3 clean coarse sand 3 mm and down). It is kept under a jute bag for another 24 hours after which it is immersed in clean water for three days. At the time of testing, these bricks are removed from water, wiped dry of any trace of moisture and placed with the flat surface *horizontal and mortar- filled face* up between three plywood sheets each of 3 mm thickness (plaster of Paris may also be used to ensure uniform surface).

   The load is applied at the rate of 140 kg/cm^2 per minute till the failure of the specimen takes place as indicated by the needle of the testing machine turning back. Average of the five test values is reported. While finding the average, any single value obtained as compressive strength which is higher than the upper value of the class of the bricks tested, should be taken only as the upper limit of the class. Values less than 20% below the average value should be discarded. The average value should not be less than the specified value.

2. ***Water absorption.*** Five bricks are taken for test. They are allowed to dry in an oven at 110° to 115° C till they attain a constant weight which usually takes place in 48 hours. They are then allowed to cool at room temperature, which generally takes 4 to 6 hours without a fan and 2 to 3 hours with a fan blowing on it and weight W_1 is measured.

They are then kept in clear water at 27 ± 2°C for 24 hours and then wiped dry with a damp cloth and weight W_2 is measured. The average percentage of water absorbed as percentage of dry weight is reported. Average of the five tests is reported. This value should not be more than the values specified in Table 2.2.

$$\text{Percentage absorption} = \left(\frac{W_2 - W_1}{W_1}\right) \times 100$$

3. ***Efflorescence.*** This test should be conducted in a well-ventilated room at 18–30°C. Average value on five samples taken at random is to be reported. The brick is placed vertically in a dish 30 cm × 20 cm approximately in size with 2.5 cm immersed in distilled water. The whole water is allowed to be absorbed by the brick and evaporated through it. After the bricks appear dry, a similar quantity of water is placed in the dish, and the water is allowed to evaporate as before. The brick is to be examined after the second evaporation and reported as follows:
   (a) *Nil.* When there is no perceptible deposit of salt.
   (b) *Slight.* When not more than 10 per cent of the area of brick is covered with salt.
   (c) *Moderate.* When there is heavy deposit covering up to 50% of the area of the brick but unaccompanied by powdering or flaking of the surface.
   (d) *Heavy.* When there is heavy deposit covering more than 50% of the area of the brick accompanied by powdering or flaking of the surface.
   (e) *Serious.* When there is a heavy deposit of salts accompanied by powdering and/or flaking of the surface and this deposition tends to increase in the repeated wetting of the specimen.

   Bricks for general construction should not have more than slight-to-moderate efflorescence.
4. ***Dimensional tolerance.*** Twenty whole bricks are selected at random to check measurement of length, width, height, etc. These dimensions are to be measured in one or two lots of ten each as shown in Figure 2.2. Variations in dimensions are allowed only within narrow limits, ±3 % for class one and ±8% for other classes.

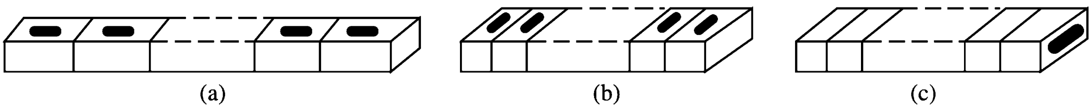


Figure 2.2 Tolerance of bricks (20 numbers used) (a) Measurement of length (b) Measurement width (c) Measurement of height.

5. ***Hardness.*** A scratch is made on the surface of the brick with the finger nail. In a good brick, no impression will be left on the surface.
6. ***Soundness.*** Two bricks are taken, one in each hand, and they are struck with each other lightly. A clear ringing sound should be produced and the bricks should not get break. All the above tests except the first one can be carried out in the field.
7. ***Structure.*** A brick is broken and its structure can be examined.

SUMMARY

Bricks are very important in building construction. We must be able to recognize the quality of bricks by inspection at the site. Generally, 250 to 300 bricks are used for construction of one square metre of plinth area of residential buildings. Care should be taken to see that we do not use bricks with salts (efflorescence) as it can give much trouble at later years.

REVIEW QUESTIONS

1. Give a brief account of the changes that take place when a wet clay block is heated from room temperature to above 1300°C to make bricks.
2. What is meant by *nominal dimension* of a brick, what is the maximum mortar thickness you allow in brickwork? What are the actual dimensions and weight of bricks that are commonly used in your region?
3. What are the three types of classifications of common bricks? Describe the test for efflorescence for bricks?
4. What are the field tests to find the suitability of bricks for construction? What is the compressive strength of the common brick that you get at your locality?
5. What are light-weight bricks? Where are they commonly used?
6. Write short notes on:
   (a) Frog in a brick
   (b) Moulding of bricks
   (c) Modular bricks
   (d) Nominal size of bricks
   (e) Sampling of bricks for testing dimensional tolerance.
   (f) Light-weight claybricks
   (g) Efflorescence in bricks
   (h) Stock bricks.

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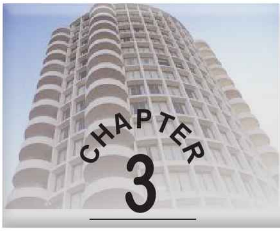
[1] IS 1077–1997: *Common Burnt Clay Building Bricks—Specification.*

[2] IS 2117–1991: *Guide for Manufacture of Hand-made Common Burnt Clay Building Bricks.*

[3] IS 3495–1992 *(Parts 1 to 4): Methods of Tests for Burnt Clay Building Bricks.*

[4] IS 3102–1971: *Classification of Clay Solid Bricks.*



Cement and Concrete Blocks

3.1 INTRODUCTION

Cement and concrete blocks are also used for masonry construction. They are available in three types namely solid, hollow and cellular. They are called hollow blocks if the percentage of voids is more than 25% Blocks with voids less than 25% are only perforated blocks. The term 'cellular concrete blocks' especially refer to light-weight aerated concrete blocks as described in Section 3.3. Concrete blocks are usually made large in size so that the blockwork is faster and consume less cement in joints than the brickwork. These blocks are extensively used for compound walls and non-loadbearing walls. Specially made hollow blocks are also used for load bearing walls. Such works are useful in reducing the deadload of masonry in buildings. Blocks can be also with cement and sand called cement-sand blocks or with soil and cement called soil cement blocks. These are of low strength and used for low cost construction.

The main disadvantage of concrete blocks is shrinkage due to movement of moisture which is absent in bricks. In addition, as these blocks are much larger in size than bricks, any foundation movement will cause blockwork to crack more than the brickwork. Hence, the first important point to remember in blockwork is that *the mortar strength should not be high*. It should not be more than the strength of the blocks. With high mortar strength, the cracks will be few and very large, but with weak mortar, they will be small and distributed.

The second point to remember is that in construction, we should use only blocks which have been cured properly for at least 14 days and dried for 4 weeks. All the initial shrinkages should have taken place by then. For the same reason, we do not wet the blocks (as in case of claybricks) when we place them for masonry construction.

A third point to remember is that ordinary unreinforced blockwork in walls is very weak for resisting lateral loads that are caused due to expansion of roof or due to earthquake and cyclones (see Section 3.7). Hence, blockwork, especially ordinary cement sand blocks and soil cement blocks, should not be used as loadbearing walls for concrete slab roof which tends to expand and contract with temperature. Such blockwork should be roofed over by trusswork or other means in which the loads do not come directly on the walls. Otherwise, we should either select specially-designed blocks or we have to introduce steel reinforcements to take care of these lateral effects.

Soil blocks (made from stabilized soil) and mortar blocks (made from mixture of soil and sand) are commonly used only for low-cost housing schemes and compound walls. They have very little strength. It is of the order of 1.5 N/mm^2 only, so that they cannot be made to bear any substantial load. They should not be used with solid R.C. roofs but only under light roofs (like A.C. sheet on wooden rafters) which does not produce any thermal effect on the walls. In this chapter, we will mainly deal with concrete blocks and also light-weight cellular blocks. We will examine only the IS specification and the list of tests to be made to determine the quality of concrete blocks. IS 2185 "Specifications for Concrete Masonry Units – Part I Hollow and Solid Concrete Block" should be referred to for details on the subject.

3.2 MANUFACTURING OF CONCRETE BLOCKS

The concrete mix for concrete blocks shall not be richer than one part of cement to six parts of volume of combined aggregate. Lean mixes up to 1:8 are also commonly used. Bureau of Indian Standards recommends a fineness modulus (see Section 13.5) of the combined aggregate between 3.6 to 4. Coarse aggregate of size 6 to 12 mm is generally used. Sixty percent fine and forty percent coarse aggregates is the mix recommended. The choice of aggregates for block is of utmost importance as cost of aggregates account for a large part of the total cost. Hence, "baby jelly" aggregates that are not generally used for conventional concrete work are found of much use in making these concrete blocks. They can be hand-made and also preferably machine-made. A simple machine can make up 1600 blocks in an eight-hour shift. The cast block is then cured in a water tank or yard for at least 14 days. When immersed in the tank, the water shall be changed at least every 4 days. After curing, the blocks are dried for a period of 4 weeks before being used on the work. They should be stacked with voids in the horizontal direction to facilitate easy drying. Otherwise, they should be steamcured and dried. There are only a few modern factories in India that use steamcured in manufacturing of concrete blocks. This process allows the complete shrinkage of the block to take place before they are laid on the wall. This is very important. As already indicated, freshly-made and uncured concrete blocks should never be allowed on the work.

3.3 DIMENSIONS AND TOLERANCES

As in case of bricks, a block is referred by its nominal dimensions. The term "nominal dimension" means that the dimension includes mortar thickness of 10 mm also. In special cases, where finer joints are specified, the mortar thickness is limited to 6 mm.

The *nominal dimensions* of concrete block according to B.I.S. are as follows (Figure 3.1)

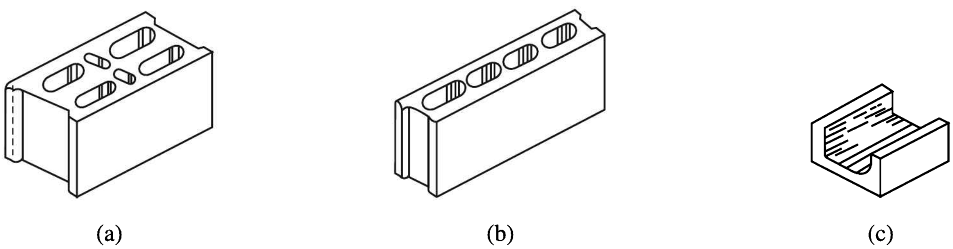


Figure 3.1 Concrete blocks (a) and (b) Hollow concrete blocks nominal length 390 mm and height 190 mm. Thickness for load bearing walls 190 mm, compound walls 140 mm, filler walls 90 mm. (c) Lintel block for R.C. Lintels.

Length – 400, 450, 500 or 600 mm
Height – 200 or 100 mm
Width – 50, 75, 100, 150, 200, 250 or 300 mm

(Actual sizes will be less by 10 mm the mortar thickness)

In addition, blocks are also made in half lengths. The maximum variation allowed is ±5 mm in length and ±3 mm in height and width. These dimensions can easily be achieved in machine made blocks. The width of blocks meant for load-bearing walls will be 200 mm and for parapet or filler walls, it is usually 100 mm.

In Table 3.1, the following are the thicknesses of the faceshell and the webs.

Table 3.1 Minimum Face Shell and Web Thickness

Block width (mm)	Faceshell thickness (mm)	Web thickness (mm)
Over 200	35	30
200–150	30	25
150–100	25	25
100 or less	25	25

Blocks can also be made with decorative facings also.

3.4 CLASSIFICATION OF CONCRETE BLOCKS

1. ***Hollow concrete blocks*** (Open and closed cavity types). These blocks are classified by I.S. into the following three grades.
   (i) *Grade A*. These blocks are used for load-bearing walls. They should have a minimum density of 1500 kg/m^3. They should be manufactured for minimum specified compressive strength of 3.5, 4.5, 5.5 and 7.0 N/mm^2 in 28 days.
   (ii) *Grade B*. These are also used for load-bearing walls. They may have a density below 1500 kg/m^3 but not less than 1000 kg/m^3. They are made for specified compressive strength of 2.0, 3.0 and 5.0 N/mm^2 in 28 days.
   (iii) *Grade C*. These are used for nonload, bearing walls, and its density is not less than 1000 kg/m^3. They are made for specified strengths of 1.5 N/mm^2 in 28 days.

   These blocks can also be made with decorative facings like fluted facing to give aesthetic effects.
2. ***Solid concrete blocks.*** These blocks are used as load-bearing walls. They should have a density not less than 1800 kg/m^3 and should be manufactured for specified concrete strength of 4.0 and 5.0 N/mm^2 in 28 days.
3. ***Paver blocks.*** These blocks are solid concrete blocks of various shapes specially made for exterior groundpaving on side walls, drive ways, parking lots, industrial floors, petrol pumps, etc.

3.5 STORAGE OF BLOCKS

As these blocks can absorb moisture by wetting and shrinking on drying, they should be protected from rains while being stored and also when walls are being built.

3.6 AUTOCLAVED AERATED CONCRETE BLOCKS

These blocks are also known as *light-weight hollow blocks.* They are prepared as solid blocks from cement, water and materials like groundsand, pulverized fly ash together with additives to aerate and stabilize the air bubbles. In some cases, aluminium powder, 0.12 to 0.25 per cent by weight of cement, is added to produce hydrogen bubbles when it reacts with the lime in the cement. The stabilizer can be soap. The resultant mixture is a thick liquid (slurry) which is then poured into steel moulds to form large cakes. After a few hours, this mixture sets and can be cut into a series of individual blocks of required size by means of taut steel wires. The blocks are then autoclaved at 10 to 15 atmospheric pressure in high temperatures for about 18 hours. They can be made to different strengths up to 7 N/mm^2 or more, but higher the strength, more will be its density. Very light blocks for partition and moderate-weight blocks for light loadbearing walls can be obtained from these blocks. As the material is obtained by autoclaving, the resulting structure of cement products is crystalline, which does not shrink on drying. The autoclaved cement product is different from the product obtained by normal wet curing or by ordinary steam curing.

3.7 USE OF BLOCK MASONRY IN BUILDINGS

Block masonry must be used after taking all the necessary precautions and also only in situations they are suitable for. For example, unless they are properly reinforced, their performance in earthquake and cyclonic regions is very poor. In some countries like Australia, unreinforced blockwork is not allowed to be used in cyclonic areas. Hollow block masonry is used extensively in India as filler walls for framed buildings. They weigh less than the brick walls and are cheaper than the brickwork in overall cost. The work can also be executed faster. In compound wall construction, they need not be plastered. However, it is difficult to fix fittings like washbasins, etc. to these walls so that such portions of a building are usually constructed with brickwork. The concrete blocks have the following advantages over claybricks.

1. One concrete block 390 × 190 × 190 mm can replace 8 bricks, thus, resulting in considerable reduction in cement mortar and speed of construction.
2. Claybrick manufacturing requires excavation of good earth from fertile areas. It also involves burning of fuel. Hence, concrete blocks are more environment friendly.
3. Because of the air columns, hollow concrete blocks offer good thermal and acoustic insulation. Hence, air conditioning and insulation costs come down very much.
4. With good concrete blocks, we get a good surface finish which need not be plastered, thus saving the cost of plastering of walls.
5. A very great advantage of using hollow concrete blocks instead of solid clay blocks in wall construction is the large reduction in deadload on foundations, beams, etc. that have to be considered in structural design.
6. The strength of mortar used in blockwork need not be more than the strength of the blocks.

3.8 TESTING OF BLOCKS (IS 2185)

The usual tests prescribed for concrete blocks are the following:

1. ***Appearance.*** For testing the appearance, 20 blocks are taken for every 5000 blocks for tests. In general, the block units should be free from cracks and other defects. Faces which are to be exposed should be free of chips, cracks or other defects except that not more than 5 per cent of the consignment may contain slight cracks or small chippings not larger than 25 mm.
2. ***Dimensions.*** Twenty full size units are taken and their length, width, height and web thickness are measured. A steel scale graduated to 1 mm is used for measuring dimensions and a caliper rule graduated to 0.5 mm divisions and jaws not less than 15 mm but not more than 25 mm in length is to be used for measuring the web thickness. The dimensions should conform to the tolerances of ±5 mm in length and ±3 mm in height and width.
3. ***Block density.*** Three blocks are chosen at random and dried at 100°C in an oven. After cooling, its weight is measured correctly to 10 g and its dimensions correctly to one mm. The density should correspond to the class of the block as given in Section 3.4.
4. ***Compressive strength.*** A batch of eight blocks is chosen at random. They are tested within 72 hours after delivery and after storage in normal room air before testing. The blocks then are capped with sulphur and granular material or plaster of Paris paste (strength about 25 N/mm^2). The strength is determined by the load taken to are divided by the *gross area of the unit* which is the area of section perpendicular to the load. Blocks intended for use with their hollow cores in a horizontal direction are tested in the same direction in which they are laid in the field. Individual values should not be less than 20% of the average value specified in Section 3.4 according to the grade.
5. ***Water absorption.*** Three specimens are tested separately to find the average value. Firstly, the specimens are completely immersed in water for 24 hours. They are again weighed when completely immersed in water to find its volume. The block is taken out, allowed to be drained for one minute and weighed to find the wet weight of the specimen. It is then dried in an oven at 100–115° C for not less than 24 hours, and the dry weight is determined. The following quantities are calculated:

$$\text{Absorption in kg/m}^3 = \frac{A - B}{A - C} \times 1000$$

$$\text{Absorption per cent} = \frac{A - B}{B} \times 100 \text{ (by mass)}$$

where

A = wet mass of the block in kg

B = dry mass of the block in kg and

C = suspended immersed mass of block in kg (volume)

The water absorption should not be more than 10% of the mass. (It should be remembered that concrete blocks are never wetted like bricks for using in masonry construction.)

6. ***Drying shrinkage.*** Three specimens, are tested for average value. Generally, three or more specimens are stored in airtight containers for duplicate testing, if required. From these blocks, specimens are cut for testing. Specimens of cross section 7.5 cm × 7.5 cm in solid blocks and 7.5 cm thickness for hollow blocks are taken for testing. They are to be not less than 15 cm in length. Two reference points consisting of 5 mm diameter steel balls cemented with rapid hardening portland cement are installed at each end. The specimen is completely immersed in water of temperature 27 ± 2°C for 4 days. The test is to be conducted by using a special measuring frame with a micrometer and Invar steel rod of suitable length (See IS 2185 (Part I), 1979 Appendix E for details). The test is first made on the wet specimen and then also on the specimen after it is completely dried in an oven for 44 hours and cooled to the room temperature. The difference in lengths is determined (The specimen should be heated, cooled and measured for a number of times till a constant value of its length in the dry state is obtained). The drying shrinkage is the shrinkage as a percentage of its dry length. It should not exceed 0.1 per cent.
7. ***Moisture movement.*** The specimen used for drying shrinkage after completion of the test is immersed in water for 4 days and its elongation is measured by the same apparatus used for drying shrinkage test. The difference between dry and wet lengths is expressed as a percentage of the dry length in the moisture movement. It should not exceed 0.09 per cent.

SUMMARY

Concrete block is nowadays replacing bricks in masonry construction especially in many multistoreyed buildings. They are extensively used for construction of boundary walls and as filler walls in R.C. framework. Unreinforced block masonry construction should not be adopted in earthquake and cyclonic areas.

REVIEW QUESTIONS

1. Explain why shrinkage is important in concrete blocks. How can we reduce the bad effects of shrinkage? Why can we expect more cracking in a load-bearing wall made of concrete blocks than in one constructed with ordinary claybricks?

2. What are the advantages of using concrete hollow cellular block masonry in buildings, and what are the main precautions to be taken in their use?

3. Explain why ordinary cement and soil cement blocks should not be used for constructing walls of buildings with concrete slab roofs? What type of roots are preferred?

4. What are the usual tests specified for cement concrete blocks?

5. What are the usual dimensions of hollow concrete blocks? How will you distinguish between blocks made for loadbearing walls and for partition walls?

6. What are the advantages in using hollow concrete blocks instead of solid claybricks in building construction?

7. Write short notes on:

(a) Mortar for blockworks

(b) Drying shrinkage in concrete block

(c) Water absorption test for concrete blocks

(d) Solid, hollow and cellular blocks.

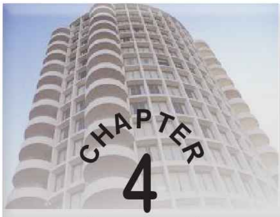
REFERENCES

[1] IS 1725 (1982): *Specification for Soil-Based Blocks Used in General Building Construction.*

[2] IS 2185 Part 1 (1979): *Specification for Concrete Masonry Units—Concrete Hollow and Solid Blocks.*

[3] IS 2185 Part 2 (1984): *Specification for Concrete Masonry Units—Hollow and Solid Light Weight Concrete Blocks.*

[4] IS 2185 Part 3 (1984): *Specification for Concrete Masonry Units—Autoclaved Cellular (Aerated) Concrete Blocks.*



CHAPTER 4

Lime

4.1 GENERAL

Lime used in building construction is produced from calcium carbonates in the form of limestone, seashells, coral, kankar, etc. When they are burnt mixed with fuel such as coal, carbon dioxide is given off as gas, and the resulting product is calcium oxide or *quicklime*.

$$CaCO_3 \rightleftharpoons CaO + CO_2 \text{ (Quicklime)}$$

Lime is manufactured in temporary clamps which are intermittant or in kilns which are continuous in their working. Quicklime is not a stable product. If it is left exposed to air, it absorbs carbon dioxide from air and reverts back to carbonate. Hence, quicklime should be slaked to calcium hydroxide (hydrated lime or slaked lime) as early as possible to make the material stable. This is done by pouring water over quicklime. Then it swells and falls into a powder form with a hissing and cracking sound. The product is called *slaked lime* or *hydrated lime*. Chemical combination of quicklime with water is called *slaking of lime*. Making of lime putty is described in Section 4.5. The term 'lime' when used in civil engineering for describing lime mortar, etc., it is understood to refer to slaked lime and not quicklime. We have products in lime such as quicklime, sloked or hydrated lime and lime putty. In this chapter, we will deal briefly with the action, classification and preparation of lime as well as the field tests that can be carried out to test its quality. The reaction in slaking of lime is

$$CaO + H_2O \rightarrow Ca(OH)_2 \text{ (Slaked or hydrated lime)}$$

4.2 CEMENTING ACTION OF LIME

The cementing action associated with lime is produced by carbonation. Calcium hydroxide combines with the carbon dioxide from the atmosphere to form calcium carbonate which has cementing properties. The reaction is as follows.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

Sand is added in lime mortar not only to make it increase in bulk (thus leading to economy) but also, of much more importance, to make the mortar porous so that air can circulate freely through the mass to assist the carbonation. Because of the *nature of the above reaction, lime does not set without access to atmospheric air such as in conditions under water.* Thus, ordinary lime mortar is not hydraulic (A hydraulic mortar is one which will set under water and its cementing action, as in Portland cement, is due to chemical reaction with its own constituents. As discussed in Chapter 6, pozzolanas, which is a reactive silica, can combine chemically with lime and produce cementing compounds. This is a chemical reaction which can take place in the presence of moisture and without air. Lime with reactive silica present in it can, thus, set even under water, and hence, such lime is called *hydraulic lime*. Lime in which pozzolanas are naturally present or are added is called hydraulic lime. Thus, naturally occurring kankar lime is hydraulic and adding surki to fat or ordinary lime can also produce a hydraulic lime which can set under water. Kankar obtained as nodules from clay deposits contain silica, and hence, kankar lime is a hydraulic lime. In general, hydraulic lime sets under water whereas fat lime sets only in the presence of atmospheric air.

4.3 CLASSIFICATION OF LIME

IS 712–1973 classifies lime as follows:

Class A: *Eminently hydraulic lime* which can be used for structural works such as arches, domes, etc.

Class B: *Semi-hydraulic lime* which can be used for constructing masonry.

Class C: *Fat lime* that can be used for finishing coat in plastering, white washing, etc. or used for masonry mortar with addition of pozzolanic material.

Class D: *Magnesium* or *dolomite lime* is used for finishing coat in plastering and whitewashing.

Class E: *Kankar lime* produced by burning lime nodules (found in soils like black cotton soils contain silica) is hydraulic. It can be used for masonry mortar.

Class F: *Siliceous dolomite lime* is used generally for undercoat and finishing coat of plaster.

Notes:

1. Carbide lime is a by-product of manufacturing of acetylene. It can be used for mortar for plaster work, but generally it is not recommended for whitewashing unless procured fresh in the form of a paste before it dries up or is treated properly.
2. Lime containing more than 30% impurities like clay is called poor limes. An idea of the comparative strengths of mortars made of limes and cement can be obtained from Table 4.1.

Table 4.1 Strength of Standard Lime and Cement Mortars

Material	Tensile strength (N/mm^2)		Compressive strength (N/mm^2)	
	7 days	28 days	14 days	28 days
Fat lime Class C		–	–	–
Class A		–	1.75	2.8
Class B		–	1.25	1.75
Cement (33 grade)	–	–	22.0	33.0

4.4 SLAKING OF QUICKLIME TO PREPARE SLAKED LIME

As already stated, *quick lime* is produced by burning of limestone, shells, etc. The procedure of slaking of lime can be described as follows. Quicklime is heaped on a masonry or wooden platform; and water is gradually sprinkled over it till lime is slaked and reduced to powder form. During sprinkling of water, the heap is turned over and over again till no more water is to be added than required for the lime to convert into the powder form. The slaked lime is then screened through I.S. sieve 3.35 mm; and the residue, if any, is rejected. The product is slaked lime.

4.5 TANK SLAKING OF QUICKLIME TO PREPARE LIME PUTTY

Quick lime is sometimes made into *lime putty* before it is used in lime mortar. For this purpose, three large tanks are made, one of them 50 cm deep and the other two of 80 cm, the former being at a higher level so that its contents can flow into the latter by gravity. First the upper tank is filled to half of its depth with water. Quicklime is added gradually till it fills half the depth of water. Lime is added to water and not vice-versa. It is then stirred, taking care that lime is not exposed to air above the water. Mixing is continued (to about 5 minutes) till boiling has stopped and the mixture thickens. More water is added, if needed, and then the products are allowed to flow to the lower tanks.

The mixture is allowed to stand in the lower tanks for at least 72 hours. The lower tanks are made of dry brick masonry with the joints filled with sand so that the water in the slurry is partly absorbed by the ground. The excess water is thus removed, and lime putty is obtained as a paste. If protected from drying out (not coming into direct contact with atmospheric carbon dioxide), it can be stored for about two weeks. Lime putty is generally used for the final setting coat for renderings. It can also be used for making lime mortar.

Note: Hydraulic lime is slaked by adding water gradually to lime to ensure thorough slaking. It requires less water than in case of fat lime. Fat quicklime slakes to about twice in the powder form and 1½ parts of paste, while hydraulic lime slakes to 1½ times in the powder form and the same quantity as the paste.

4.6 STORING LIME

Quicklime should be kept in airtight vessels or in large heaps so that air is excluded from it as far as possible if it is to be stored at all. Slaked lime can be stored for 3 to 4 months packed in gunny bags, lined with polythene, craft paper, etc. and stored in a dry place (in weather-proof sheds with impervious floor and sides). Some specifications require that lime should be slaked not less than one week and not more than four weeks before its use.

4.7 PRECAUTIONS IN HANDLING LIME

Lime can affect the skin and also produces health hazards if breathed in. The moisture in the body reacts with lime to produce the ill effects. It is customary to use goggles, respirators gloves, boots and other protections for workers handling lime. Usually the workers oil their skin to avoid these external effects. Slaking of lime is an exothermic reaction, i.e. it produces a large amount of heat. Precautions should be taken so that it does not cause trouble to the workers and also chances of fire hazard are avoided.

4.8 TESTS FOR LIME

Tests for lime can be classified into two types—laboratory tests and field tests.

4.8.1 Laboratory Tests for Building Lime

Indian standards specify ten laboratory tests for lime in IS 6932–1973 "Methods of Test for Building Lime" (Parts 1 to 11). For details of these tests, these ten volumes can be consulted. They are too numerous to be mentioned in this book.

4.8.2 Field Tests for Building Lime

IS 1624–1974 gives a number of field tests for building lime which can be readily carried out in the field. They are as follows:

1. ***Visual examination.*** Class C lime should be pure white in colour.
2. ***Hydrochloric acid test.*** Hydrochloric acid (50 per cent strength) is poured to a levelled teaspoonful of powered lime taken in a test tube till effervescence ceases (about 10 cc will be required). It is left standing for 24 hours. The bubbling reaction indicates presence of lime and the volume of insoluble residue is indicated by the unwanted inert material (adulteration). A good thick gel formation after 24 hours standing, (which does not flow when the test tube is inverted) shows the presence of Class A lime while a gel which flows indicates that of Class B lime. In the case of Class C lime, no gel is formed.
3. ***Ball test.*** A ball about the size of an egg is made with lime and just enough water. It is stored for 6 hours and then placed in a basin of water. If it has shows expansion and disintegration in a few minutes, then it is Class C lime. If there is little expansion with a number of cracking, it can be classed as Class B. Class A lime will have no adverse effects.
4. ***Impurity test.*** A known weight of lime is mixed with water in a beaker and the solution is decanted. The residue is dried well in the hot sun for 8 hours and then weighed. If the residue is less than 10%, then the lime is good, 10 to 20% fair and above 20% poor.
5. ***Plasticity test.*** The lime is mixed with water to a thick paste and left overnight. It is spread like butter on a blotting paper with a knife to test its plasticity. Good lime is plastic in nature.
6. ***Workability test.*** It is judged by making 1:3 lime sand mortar and throwing it on a brick wall by a trowel and examining its sticking quality. If it sticks well, then its workability is good.

4.9 PREPARATION OF LIME MORTARS

Chapter 10 deals with this subject in detail.

SUMMARY

Hydraulic lime has the ability to set under water. However, pure fat lime mortar sets only when it is exposed to air and can absorb the carbon dioxide from the air to form carbonates. This is the reason why lime should be mixed with sand to form lime mortar which is porous and will have access to air. Quicklime is generally made into lime putty to make lime mortar. The preparation of lime mortar is dealt with in Chapter 10.

REVIEW QUESTIONS

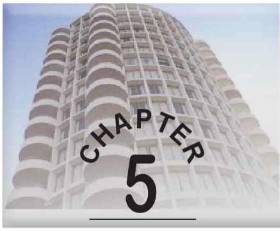
1. Explain the mechanics of the setting and cementing action of lime. Compare it with that of Portland cement.
2. What is meant by hydraulic lime? How can it be obtained? In which situations, do we have to use hydraulic lime? How can we make fat lime hydraulic?
3. Write short notes on:
   (a) Quicklime
   (b) Hydrated or slaked lime
   (c) Lime putty
   (d) Hydraulic lime
4. What are Class A, B and C limes? Give the field tests that can be performed classify lime into Class A, B and C.
5. How do you proceed to get (a) lime putty and (b) quicklime (c) slaked lime.

REFERENCES

[1] IS 712–1984: *Specification for Building Limes.*

[2] IS 6932–1973 *(Parts 1 to 11)*: *Methods of Tests for Building Limes*

[3] IS 1624–1986: *Methods of Field Testing of Building Limes.*



CHAPTER 5

Cement

5.1 GENERAL

Cement is the most important material in building construction. To a layman, the term "cement" means Portland cement. The name "cement" refers to the material manufactured from limestone and clay and made available in powder form, which when mixed with water can set to a hard durable mass even under water. In India, from very early times, hydraulic lime was produced by burning kankar nodules (which is lime mixed with clay). Such hydraulic lime was used for the construction of ancient irrigation works in India. However, it was John Smeaton, a British engineer, who in 1756, patented the artificial production of cement obtained by heating a mixture of lime and clay. As the resulting material looked like the stone in Portland, he called it Portland cement. The modern method of manufacture was later patented by Joseph Aspdin in 1824. Manufacturing of cement was started in India in 1904 but was fully established only in 1912. Till then, for many years, we were importing cement from England. Nowadays in India, most cements marketed in bags are only a mixture of portland cement and pozzolana like flyash. OPC is supplied only in bulk as for RMC plants.

5.2 MANUFACTURE OF PORTLAND CEMENT (SILICA, ALUMINA AND IRON OXIDE)

Cement is manufactured from limestone and clay by the old wet process or the new dry process. In the old *wet process,* the limestone is crushed and the clay is made into a liquid form by addition of water. They are again mixed together in correct proportions and very finely ground. The mixture is called *slurry*. It is then conveyed into tanks and then to a long cylinderical rotary kiln where it is *gradually heated* to high temperature of 1300 to 1500°C. In this process, it is converted to clinker (fused lumps), which is then ground in ball mills and tube mills to an exceedingly fine powder to form cement.

However, in modern cement plants, the above wet process is being replaced by the *dry or semi-dry process,* in which the limestone and shale are crushed to powder form and blended in correct proportions. This is then mixed in the dry form by means of compressed air. This mixture behaves like a fluid (fluidized bed) and is sieved and sent to the calciner which converts it into clinker which is ground to cement. The dry process consumes less fuel (100 kg of coal per ton of cement compared to 350 kg of coal for the wet process). Modern cement plants incorporate a number of automotive devices for quality control of the constituents of the cement. The main constituents in cement that give cementing properties are the following four compounds:

(a) Dicalcium Silicate $2CaOSiO_2$ denoted as (C_2S).
(b) Tricalcium Silicate $3CaOSiO_2$ denoted as (C_3S).
(c) Tricalcium Aluminate $3CaOAl_2O_3$ denoted as (C_3A).
(d) Tetracalcium Aluminium Ferrite $4CaOAl_2O_3Fe_2O_3$ denoted as (C_4AF).

(Generally, the content of C_2S is about 25 per cent and that of C_3S about 45 per cent of the cement.)

5.2.1 Setting Action of Cement

When water is added to cement, the ingredients of cement *react chemically* and form complicated compounds. First, a cement paste in formed which slowly thickens. In about 30 minutes, it is said to have attained its *initial set*. In about 10 hours, it becomes rock hard and is said to have reached its *final set*.

As the chemical reaction takes place under water (unlike setting of lime described in Chapter 4) cement is called hydraulic, i.e. set under water. The effect of variation of the different compounds in the cement is described in the next section.

5.3 COMPOSITION OF PORTLAND CEMENT

The cementing properties of cement develop due to chemical reaction of the above–mentioned compounds. Depending on the raw materials, type of firing, etc., the proportion of these various constituents can be made to differ and the resulting product will also give differing properties. Of all the main constituents of cement, C_3S and C_3A control the setting and early strengths and heat of hydration. The compound C_2S is responsible for strength at longer ages. C_3A also generates higher heat than other compounds. Increase in C_3S results in higher long-term strength and high heat of hydration. *If C_3A and C_4AF are kept low, then the resistance to chemicals such as sulphates is increased.* Portland cement itself is produced in different types by varying the proportions of the constituents of cement as shown in Table 5.1.

Table 5.1 Composition of Portland Cement

Description	Approximate percentage of constituents			
	C_2S	C_3S	C_3A	C_4AF
1. Normal or ordinary	25	45	12	8
2. Rapid hardening	26	45	5	15
3. Low heat	31	21	6	14

Notes.

1. We should note the difference between setting of lime (given in Chapter 4) and setting of cement. Cement after its final set can set strong under water. Whereas the cementing property of lime depends on its exposure to air, the cementing property of

Portland cement is due to the chemical reaction between its various constituents *in the presence of moisture*. It is absolutely essential that moisture should be present in the initial stages for the development of strength of cement. This process of supplying this kind of environment is known as curing, Thus, curing of the products of cement is very important in all the works connected with cement, like construction of masonry, plastering, concreting, etc.

2. The total percentage of C_2S and C_3S in all types of Portland cements is around 70 per cent, so that even though the strength development of two cements at early stages may be different, the final strength obtained after long periods of time may not be different. However, removal of formwork, prestressing of concrete depends to a large extent on the early strength of concrete.
3. When producing low-heat Portland cement the percentage of C_2S is increased and that of C_3S and C_3A is decreased. This type of cement is of particular use in construction of dams, massive foundation, etc. to reduce the production of heat.
4. *Reducing* C_3A *increases sulphate resistance but the 7 day and 28 day strengths also get lowered as compared to the ordinary Portland cement.* Sulphate-resisting Portland cement has less than 5% C_3A. This type of cement is recommended for sewer works.
5. Rapid hardening cements compared to ordinary cements have more or less the same composition except that the latter is more finely ground and may sometimes contain higher percentage of C_3S. The increased fineness increases the 7 day strength.

5.4 WHITE CEMENT

White cement is very much used for making of mosaic tiles, coloured cements, etc. White cement is made from chalk or limestone or shelllime free from impurities and white clays like china clay (kaoline clay) free from oxides of iron, manganese, etc. Shelllime is on ideal raw material. In some factories, oil is used instead of coal as fuel. Grinding is also done in a special mill to avoid iron oxide. White cement is the base for all coloured cements. However, all concretes made from coloured cement tend to fade with time due to deposition of lime salts on the surface. Hence, the best coloured concretes are those in which naturally coloured aggregates are relied upon for the colour effect and the colour of the cement should play only a secondary role.

5.5 TYPES OF CEMENT PRODUCED IN INDIA

Ordinary portland cement (OPC) and Portland pozzolana cement (PPC), (the latter being a mixture of Portland cement and 15 to 35% pozzolanas,) are the types of cements prescribed in India. Even though formerly it was mandatory in India to indicate on the cement bags the nature of its contents (OPC or PPC) nowadays this is not legally necessary. Only the grade of the cement is marked on the bag. Most cements sold in India is portland cement mixed with various proportions of pozzolanes like flyash. Cement is specified by its grade, i.e. the mortar cube strength in N/mm^2 in 28 days. (We use compression strength of 1:3 cement mortar as cubes of 50 cm^2 area (7.06 cm) in 28 days for defining strength.) Thus, Grade-33 cement (C-33) means cement with standard mortar cube strength of 33 N/mm^2 in 28 days. In India, cement is available in the market in bags of 50 kg. The tolerance allowed is ±2.5% in weight per bag and an overall tolerance of ±0.5% per wagon load of 20 to 25 tonnes. In case of massive works like dams, it is to be supplied in bulk and is stored in large bins at the site. The following are the IS specifications.

1. Ordinary portland cement (OPC) in 3 grades
   (a) Grade 33 – IS 269-1989 designated as C-33
   (b) Grade 43 – IS 8112-1989 designated as C-43
   (c) Grade 53 – IS 12269-1987 designated as C-53
2. Portland pozzolana cement (PPC) (a mixture of OPC and Pozzolanas)
   (a) IS 1489 (Part I)-1991 (flyash-based)
   (b) IS 1489 (Part II)-1991 (calcined clay-based)
3. Sulphate-resisting cement–IS 12330-1988
4. Portland slag cement–IS 455-1989 (PSC)
5. Low-heat cement–IS 12600-1989
6. Rapid-hardening cement–IS 8041-1990
7. Concrete sleeper-grade cement–IS T40-1985
8. Coloured cement–White Cement–IS 8042-1989
9. Oil well cement–IS 8229-1986
10. Hydrophobic cement–IS 8043-1991
11. Masonry cement–IS 3466-1988
12. High-alumina cement–IS 6452-1989
13. Supersulphated cement–IS 6909-1990
14. Expansive cement
15. Quick-setting cement.

The more important types of cement are the following:

1. ***Ordinary Portland cement (OPC).*** About 70% of cement produced in India was of this category and in 3 grades, viz. Grade 33, 43 and 53 as already stated above. However pure portland cement is generally not marketed nowadays in bags.
2. ***Portland pozzolana cement (PPC).*** This type of cement is the most common type available now in the market and is made by blending 10 to 25% reactive pozzolana like flyash or calcined clay with OPC. Addition of pozzolana makes cement sensitive to curing and PPC requires longer curing than OPC. This type (PPC) is also available in three grades.
3. ***Sulphate-resisting Portland cement (SRPC or SRC).*** This kind of cement is produced in small quantities in India. It is special OPC with less than 5% C_3A and are superior in resistance against sulphates. Cements called Birla Coastal comes in this category. They should not be confused with supersulphated cements (SSC) made from blast furnace slag, calcium sulphate and small quantities of OPC. (SSC is not recommended for use in places with temperatures above 40°C as in India.) IS 456-2000 recommends that where chlorides is encountered along with sulphate in foundation soil or ground water, OPC with C_3A content 5 to 8 per cent is desirable to be used instead of supersulphate-

resisting cement. Alternately, Portland slag cement having more than 50% slag or a blend of OPC and slag cement (which has been found to be of good performance) is recommended.

4. ***Portland blast furnace slag cement or Portland slag cement (BFSC or PSC).*** This type of cement constitutes about 10% of cement produced in India. The slag forms 25 to 60% of the cement. Every ton of cast iron produces about 0.3 tons of blast furnace slag which can be used in the cement industry. During its setting, the $Ca(OH)_2$ liberated by OPC hydration acts as an activator for the slag. They are also less costly than OPC. Even though it is equated with OPC, it behaves more like PPC and *has lower heat of hydration and better sulphate resistance*. At present, the BFSC cement produced in India is only Grade-33 and there are proposals to make Grade-43 cements with 45–70% slag content. Blast furnace slag cement with more than 50% slag has good sulphate resistance too.
5. ***Hydrophobic cement.*** In places of high rainfall and humidity, normal cement tends to set when stored due to moisture present in the atmosphere. By grinding the cement clinker with a water-repellent film forming substance like oleic acid, a water-repellent film is formed around cement particles during the manufacturing itself. This prevents setting of cement during storage. During mixing with aggregates, this film is broken and cement behaves as ordinary cement.
6. ***Blended cement.*** For economy, a mixture of Portland cement, blast furnace slag and flyash is allowed to be used in some countries. It is known as blended cement. This type of cement is not marketed in India.

5.5.1 Grades of Cements Available in India

In the U.S.A. and U.K., cement is covered by one specification, whereas in Germany, it is available in 3 grades. The German practice has also been accepted in India and it came about as follows:

Till around 1973, only Grade-33 cement was available in India. However, between 1973–75 the Indian Railways adopted the use of prestressed concrete sleepers in a big way for running the high speed trains. It was soon apparent that the common Grade-33 cement available in the market was inadequate to develop the needed minimum characteristic concrete strength of about 50 N/mm^2 required for the purpose. Hence, the railways developed their own specification for "sleeper cements" with a minimum cement strength of 52.5 N/mm^2 in 28 days. Some of the factories in India came forward to make these type of cements for the railways, which made them available only to the sleeper manufacturers. Very soon, with the advancement of cement technology, more and more factories found it easy to manufacture higher grade cements with their modernized cement plants. Thus, we have the following types of cement in India:

1. Grade-33 as per IS 269 (1989)—C 33
2. Grade-43 as per IS 8112 (1989)—C 43
3. Grade-53 as per IS 12269 (1987)—C 53
4. Sleeper cements as per IRS-T40-85 (this will be between C 43 and C 53) formerly supplied only to the railways, but nowadays freely available as C 53 special cement.

The easily available cement today is of Grade-43. It should be noted that the testing procedures used in India are different from those in U.S.A., where cylinders are used so that the 53-Grade cement produced in India would give approximately 25 to 30% less strength as per ASTM standards. The compressive strength developed by the cements with time is shown in Table 5.2.

Table 5.2 Compressive Strengths of Mortar Cubes of Different Grades of Cement in N/mm^2

Age (in days)	Grade			Sleeper cement	
	Grade 33	Grade 43	Grade 53	Code	Actual
		Recommended values			
3	16	23	27	–	40.3
7	22	33	37	37.5	55.3
28	33	43	53	–	70.3
	Observed laboratory values as percentage of 28-day strength				
3	30–40	50–60	70–80		
7	50–65	65–80	80–90		
28	100	100	100		
90	100–125	105–115	100–105		
180	115–130	110–120	105–110		

5.6 STORAGE OF CEMENT

In major construction works, it will be always necessary to keep a good stock of cement at site. The cement shall always be stored in such a manner as to be easily accessible for proper inspection. It should be stored in suitable weather-tight buildings which can protect it from dampness. It may be stored as bags in sheds or in bulk in silos made of concrete or steel. *When storing cement in bags*, the following guidelines should be observed:

(a) Storage for long periods should be avoided and storage during rainy season should be as minimal as possible. The shed size is designed usually to hold the maximum quantity of cement to be used *in any two consecutive weeks.*

(b) Godowns should never be damp and cement bags should not be piled against the wall. A space of 60 cm all-round should be left between the exterior walls and the stacks. The distance between two consecutive stacks should be the minimum to reduce circulation of air.

(c) They should be piled off the floor on wooden planks so as to be clear of the floor by at least 10 to 20 cm.

(d) The number of bags in one pile should not usually be more than ten to avoid lumping under pressure. Otherwise, it may also become cumbersome to stack or remove them. In no case, the of the stack height should be more than fifteen bags.

(e) Owing to pressure on the lower layer of bags, the cement may develop what is known as “warehouse pack”. This can be removed by rolling the bag when it is taken out of the stack for use. On account of "warehouse pack," the bags need not be moved and restacked, as there is no advantage in doing so.

(f) If the pile is to be more than 7 bags high, then the bags may be arranged in header and stretcher fashion (that is alternatively lengthwise and crosswise) so as to tie the piles together and to lessen the danger of toppling over.

(g) For safety during rains or when storing cement for unusually long periods, the stack should be enclosed completely in 700 gauge polythene sheet, tarpaulin or any other suitable water-proofing material. The flap should be completely closed on top of the stack.

(h) While removing bags from storage, the older cement should be removed first. For this purpose, each consignment as it comes should be stacked separately and a *placard* indicating the date of arrival should be pinned into the pile.

(i) Bags should be removed from two or three tiers rather than all from one tier. If the piles are thus stepped back, then there is less chance of overturning to occur. While removing the bags, the "first in, first out" rule should be applied.

(j) If different brands of cement are meant to be used on one work, they should be stacked separately. Cement which has become caked or in any way damaged shall, on no account, be used on the work.

(k) The weight of Portland cement for standard data purposes is taken as 1430 kg per cubic metre. One tonne of cement shall comprise of 20 bags, each bag weighing 50 kg. Each bag can be assumed to contain 0.035 cubic metre or 35 litres and 1.25 Cft of cement in volume.

Storage of cement in large work like dams or ready mix plants, etc. is made in special bins. Cement is dispatched in bulk in specially-built trucks from which it is pumped into storage bins by special pumps.

5.7 ADULTERATION OF CEMENT

In India as we have already noted nowadays, cement is sold in bags without special marking to its contents on the bag except the grade. Pozzolana cement is the cement in which at least 10% Pozzolana by weight has been added. The maximum Pozzolana allowed to be mixed is 35% and most of the pozzolana cements sold in the market has an addition of 20% of Pozzolana (i.e. it is only 70 to 80% pure cement). This can lead to adulteration of cement. No standard test is available for determination of pozzolana in cement. An easy way for field checking of the adulteration of cement by clay, silt, etc. is to burn a sample of cement for about 20 minutes on a steel plate on a stove. Adulterated cement changes its colour while pure cement (which is a product of intense heat) does not change its colour on heating to high temperature. However, this test cannot detect the addition of pozzolana in cement as it is also produced under high temperatures.

5.8 SAMPLING AND TESTING OF CEMENT

Samples for laboratory tests should be taken within one week of delivery and all the tests should be commenced within one week of sampling. When it is not possible to test the samples within one week, the samples shall be packed and stored in airtight containers till the time when they are tested. Physical and chemical testing of cement can be done only with the help of a proper laboratory. When sending samples from the site, care should be taken because the samples represent the lot. Sometimes, a bag of cement is chosen at random from a consignment and sent for testing purposes. However, the total quantity of cement required for one set of laboratory tests is approximately 10 kg only. In most of the large construction sites, routine testing of cement is adopted as a method for proper work control. Even though in most of the cases only strength requirements are insisted on, it is strongly recommended from experience that it is preferable to insist on fineness requirements also for proper control of quality of the cement. In any case, cement which has been in storage for more than three months after manufacturing should be always tested for its fitness before use.

5.9 TEST CERTIFICATE FOR CEMENT

Weekly test certificates are usually sent by the marketing divisions of the manufacturers regarding the physical and chemical analysis of the cement *dispatched* from the factory. The following are the specifications to be satisfied for 43 and 53 Grade cements which nowadays are the commonly used cements (Table 5.3). The temperature within which physical tests are to be carried out is 27 ± 2°C and it is required to record the actual temperature during the test in the certificate.

Table 5.3 Test Requirements of Common Cements
A. Physical Analysis

S.No.	Name of test	Grade 33	Grade 43	Grade 53
1.	Fineness as specific surface (m^2/kg)		$\nless$ 225	
2.	Soundness			
	Expansion of unaerated cement			
	(a) By Lechatelier method		$\ngtr$ 10 mm	
	(b) By autoclave		$\ngtr$ 0.8%	
3.	Setting time			
	(a) Initial set		$\nless$30 min	
	(b) Final set		$\ngtr$ 600 min	
4.	Compressive strength			
	(a) 3 days Mpa (N/mm^2)	16	23	27
	(b) 7 days Mpa (N/mm^2)	22	33	37
	(c) 28 days Mpa (N/mm^2)	33	43	53
5.	Also state the following temperature during testing		27°± 2°C (Standard)	

(*Contd.*)

Table 5.3 Test Requirements of Common Cements (*Contd.*)

	B. Chemical Analysis			
1.	Lime saturation factor (LSF) (%)		$\nless$ 0.66 and $\ngtr$ 1.02	
2.	Aluminium iron ratio (%)		$\nless$ 0.66	
3.	Insoluble residue (IR) (%)	$\ngtr$ 4	$\ngtr$ 2	$\ngtr$ 2
4.	Magnesia (MgO) (%)		$\ngtr$ 6	
5.	Sulphuric anhydride (SO_3)		2.5% when $C_3A \leq 5$ and $\ngtr$ 3% when $C_3A > 5$	
6.	Loss on ignition (%)	$\ngtr$ 5	$\ngtr$ 5	$\ngtr$ 4
7.	Alkalis		$\ngtr$ 0.6%	
8.	Chlorides		$\ngtr$ 0.05%	
9.	C_3A		State value	

Notes: (1) L.S.F. = Ratio of $\dfrac{CaO - 0.7SO_3}{2.8SiO_2 + 1.2Al_2O_3 + 0.65Fe_2O_3}$

(2) C_3A content = $2.65\,Al_2O_3 - 1.69\,Fe_2O_3$

(Refer Section 5.10.7 and Section 5.3 Item 4)

5.10 DESCRIPTION OF PHYSICAL TESTS (IS 4031: PARTS 1 TO 11)

The physical tests are specified in Parts 1 to 11 of IS 4031. We shall briefly deal with some of the main laboratory physical tests in the following sections. The concerned Indian Standards should be consulted for details of these tests. In engineering college laboratories, only physical tests are carried out. Chemical tests are carried out in cement factory laboratories and they are shown in the test certificates for each batch manufactured and supplied by the manufacturer to their field agents.

5.10.1 Test for Fineness

The first requirement is that 90% of cement should pass IS 90 microns. Indian Standards also specifies fineness test by Blaine's Air-permeability method as described in IS 4031-1968. The principle is based on the relation between the rate of flow of air through a cement bed and the surface area of the particles comprising the cement bed of a given porosity. The finer the cement, the more the surface area and less the porosity in the permeability test. The Blane's apparatus is shown in Figure 5.1. As shown in Table 5.3 it should be at least 225 m^2/kg.

5.10.2 Test for Normal or Standard Consistency

Many tests for cements like soundness, setting time are to be carried out with cement to which water required to produce what is called the "normal consistency". Normal consistency is determined by the apparatus called Vicat's needle. It is the consistency at which the Vicat plunger G of 10 mm diameter and 50 mm length will penetrate 33–35 mm within 3 to 5 minutes of mixing. The test procedure is to carry out at least three trial experiments by mixing the cement with distilled water varying from about 24 to 27 per cent of the weight of cement. The Vicat's needle test apparatus is shown in Figure 5.2.

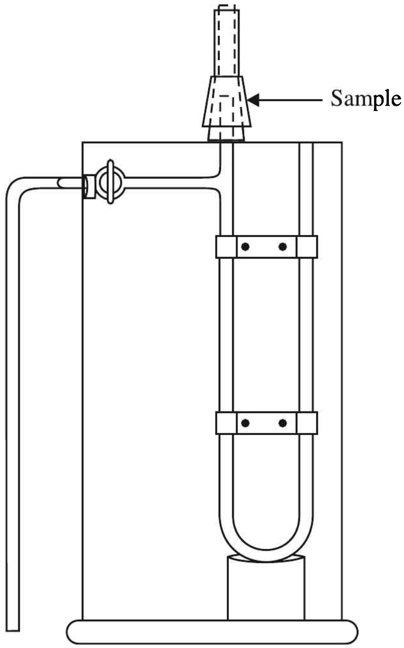


Figure 5.1 Blanes air permeability apparatus.

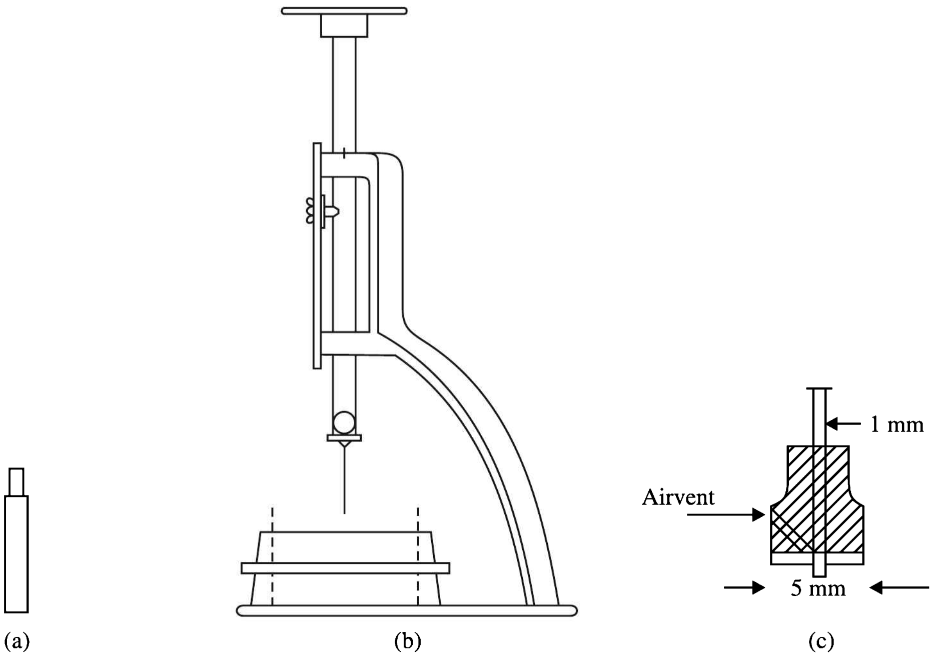


Figure 5.2 Vicat apparatus with various plungers (a) 10 mm dia needle for normal consistency (b) 1 mm square needle for initial set (c) 5 mm dia needle for final set.

5.10.3 Test for Soundness

The soundness test is an indication of excess of lime caused by inadequate burning of cement or excess of magnesia or sulphates. Excess of these substances is harmful and thus, not allowed in cements. The following two types of tests are used for testing for soundness.

(a) Le Chatelier's test (using Le Chatelier's apparatus)
(b) Autoclave test

Le Chatelier's test. Le Chatelier's test shows unsoundness due to lime only. Unaerated cement paste at normal consistency is first tested for expansion. If the test results does not satisfy requirement of 10 mm expansion, another test shall be made after aeration of the cement by spreading of the sample to a depth of 75 mm at a relative humidity of 50 to 80% for 7 days. The expansion in this aerated cement test should not be more than 5 mm.

The apparatus used is shown in Figure 5.3. Cement pastes with normal consistency is filled into the mould. After covering both sides with glass, it is first placed in water of temperature 24 to 35°C for 24 hours. It is taken out and the distance between pointers is measured. The mould is then placed in water and the water is heated to the boiling point in 30 minutes. The boiling of water is continued for one hour. The mould is then removed and after cooling, the distance between the points is again measured.

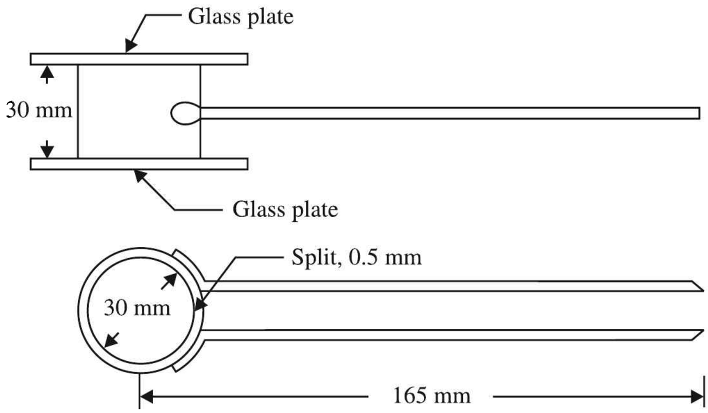


Figure 5.3 Le Chatelier's apparatus.

Autoclave test. Autoclave test is another test used for soundness of cement. It is sensitive to both lime and magnesia. All the cement having a magnesia content more than 3 per cent is to be tested for soundness by this test with unaerated cement. The test consists of heating bars made of cement paste with water of normal consistency and measuring its expansion. Effect of unsoundness of cement does not appear in the field for a considerable period of time. Hence, these accelerated tests are needed to determine them. In autoclave test, we use higher pressure and temperature to accelerate the reactions. The autoclave expansion of unaerated cement should not be more than 0.8 per cent and that of aerated cement not more than 0.6 per cent.

5.10.4 Test for Setting Time

The setting time is also determined by the Vicat's needle on cement paste of normal consistency. For this test, we use a 1 mm square needle (needle C). For this needle, the time to penetrate 33–35 mm is taken as initial setting time.

For final setting time, we use special needle F (which has a diameter of 5 mm) and the time at which this needle will not penetrate more than 0.5 mm is taken as the final set.

False set happens when the ratio of the penetration of the Vicat's C needle after 300 seconds to the penetration in 20 seconds is less than 1/2. In such cases the test has to be repeated. The temperature of water and test room should be 27 ±2°C.

5.10.5 Compressive Strength

Compressive strength of cement is a very important test. Compressive strength of cement is determined from cubes of face 50 cm^2 in area (7.06 cm cubes) made of cement mortar with one part of cement and three parts of *standard sand* (conforming to IS 650-1966) by weight and water corresponding to 25% normal consistency plus three per cent of the combined weight of the cement and sand (P/4 + 3.0 per cent weight of cement and sand). The average cube strength of three samples is taken as the test value. Strengths in 3, 7 and 28 days are to be reported. Usually 555 gm of sand and 185 gm of cement are used for the test. The procedure can be described as follows:

1. 555 gm of standard sand and 185 gm of the given cement enough to make three standard cubes are mixed with water equal to 0.25 normal consistency plus three per cent of the combined weight of the cement and sand to a uniform mix (1:3 mortar with a water cement ratio of 0.4 is also specified for this test).
2. The mortar is placed in the standard 7.05 cm size cubes and compacted in a vibrating machine for 2 minutes (The former method of ramming has now been standardized by the vibrating machine).
3. The moulds, with the mortar, is placed under a damp gunny bag or cabin for 24 hours for the cement mortar to set.
4. The cubes are removed after 24 hours and submerged in clean water for curing for 3, 7 or 28 days.
5. The cubes are tested in sets of three after 3 days and 7 days and 28 days after drying the specimen with a cloth. The strengths should conform to the specified, strength of Table 5.2.

5.10.6 Heat of Hydration (IS 4031–1968)

Hydration of cement is a chemical reaction and it produces heat. In very massive construction this effect can raise the temperature of concrete as much as 50°C. In such cases, we should use low–heat cements or adopt cooling methods. This test is, hence, required only as a check for low-heat cements. It is made by the principle of determining heat gain as in physics experiments. The test is carried out by a Calorimeter. Low heat cements should satisfy the following criteria.

(a) In 7 days, heat generated should not be more than 65 calories per gram of cement.
(b) In 28 days, heat generated should not be more than 75 calories per gram of cement.

5.10.7 Chemical Composition Tests (Test for LSF)

The Lime Saturation Factor or LSF is the most important factor. It is determined by applying the following formula to the various constituants of the given cement.

$$\frac{CaO - 0.7SO_3}{2.8SiO_2 + 1.2Al_2O_3 + 0.65Fe_2O_3} \ngtr 1.02 \text{ and } \nless 0.66$$ for Grades C-3 and Grade C-43

cements and $\ngtr$ 1.02 and $\nless$ 0.8 for Grade C-53 cement. As shown in Table 5.3 the C_3A content is also determined when the cement's sulphate resistance is also required.

5.10.8 Tests for Tensile Strength

This test was once used as a routine test for cement but has been discontinued as test for cement, but is used for testing mortars (see Chapter 10). For this test, briquettes as shown in Figure 5.4 are made from 1:3 cement mortar using standard sand and water of 8 per cent the weight of cement and sand. They are cured and the 3-day and 7-day tensile strengths are reported. It is generally specified that the 3-day tensile strength should not be less than 2 N/mm^2 and the 7-day strength not less than 2.5 N/mm^2. The briquettes are tested in a special briquette-testing machine. (The shape of briquettes for cement mortar test is shown in Figure 5.4. It has an area of 25.4 × 25 mm or 1 × 1 inch, compared to 38 × 38 mm or $1^1/_2 \times 1^1/_2$ inch for test on lime mortar).

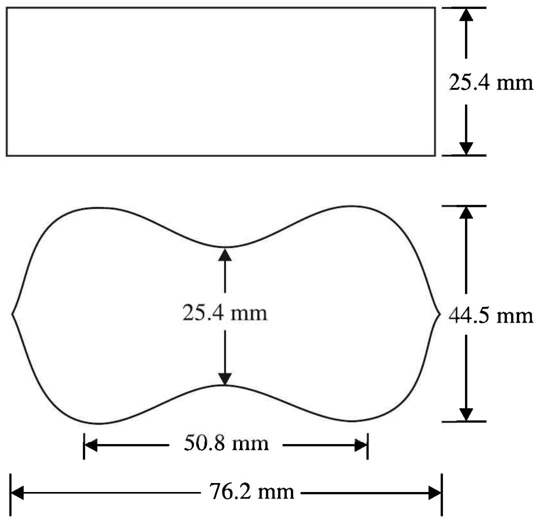


Figure 5.4 Standard cement-mortar briquette (Area 1 sq inch).

5.11 MECHANICS OF SETTING OF CEMENT

Water is an essential component to bring about the chemical reaction between the various cementing compounds in the cement. Due to chemical reactions, cement sets and then hardens with time. This chemical process is called *hydration of cement.* In this process, cement gel is also formed. It is estimated that the water required for complete hydration is only about 23 per cent of the weight of cement to form the cement compounds and another 15 per cent is used for gel formation. Thus, a total of only about 38 to 40 per cent at the most is required for hydration of cement. Any water added over and above this value will form capillary tubes (cavities) which will considerably decrease the strength of the products. With increased water-cement ratio, more capillaries are formed resulting in lower strengths. Thus, in making concrete with cement, we try to reduce the water-cement ratio to the minimum. However, from workability considerations, we may have to use water more than just necessary unless we use cement additives to increase workability. These problems are dealt with in Chapters 13 and 14 of this book. It is, however, very important to note that the chemical reaction in cement takes place only in humid conditions and hence, proper curing is necessary to develop the full strength of cement.

5.12 DEVELOPMENTS IN MANUFACTURING OF CEMENTS

Portland slag cement (PSC) has been invented to make use of the waste product from blast furnaces. The slag obtained in steel plants is chilled rapidly to form crystalline products. Which is called granulated slag. This granduated blast furnace slag is mixed with portland cement clinker and gypsum (to control setting properties) and ground to form PSC. This cement has law heat of hydration increased resistance to chemical attack. However its attainment of strength is shwer than OPC. In India today about 10% of the total production of cement is portland slag cement.

5.13 TEST FOR PRESENCE OF LIGHT MATERIALS IN CEMENT

An easy test to determine ash and in cement is to spread a handful of cement on water in a bucket. As cement particles are heavy, they will sink and particles lighter than water will float.

SUMMARY

Portland cement is, perhaps, the most used civil engineering construction material. It is available in India in three grades. As the cost of cement for a building can be high, it is advisable to use different grades of cement (of varying cost) for different types of work. It is also advisable to use the minimum amount of cement required for works such as cement mortar and cement plaster. Higher percentage of cement will give higher strength which may not be required. Because of shrinkage of cement, the higher the cement content, the more will be the shrinkage and shrinkage cracks. Higher cement strengths and higher cement contents can be thus harmful in many cases. Hence, judgement must be used in the use of the type and quantity of the cement used in building works. Some types of cements claiming as crack-resisting cements for plastering are in relity PPC with less cement content.

The three main topics of current interest in use of cement are the following.

1. Developing different kinds of cements for different applications.
2. Developing the manufacture of other types of cements like the blast furnace slag cement also called Portland slag cement (PSC) IS 455–1989.

3. Developing use of additives (like flyash and chemicals) to improve the performance of cement when used in mortars and concrete. This will reduce cost and also encourage recycling of waste products.

REVIEW QUESTIONS

1. What are OPC, PPC and PSC? What types of cements are now commonly available in India and used for reinforced concrete construction in India?

2. What is meant by Grade C-43 cement? What are the main active cementing compounds in ordinary portland cement? How do we choose a cement for sulphate resistance as for sewage work?

3. Name the important physical and chemical tests specified to be carried out on common cement? Specify the physical tests requirements that should be satisfied by all the grades of cements.

4. Indicate how cement should be stored for (a) house construction and (b) a ready mix plant.

5. Write short notes on the following:
   (a) Sampling of cement for tests
   (b) Test for setting time
   (c) Test for compression strength
   (d) Blast furnace slag cement (PSC)
   (e) Portland pozzolan cement
   (f) Heat of hydration of cement

6. Which type of cement will you recommend for (a) structural concrete, (b) cement mortar, (c) cement plaster, and (d) in foundations with high sulphate ground water.

7. Describe the mechanism of strength development of cement. How is it different from that of lime? Explain how higher water cement ratio reduces the strength of cement.

REFERENCES

[1] IS 269–1989: *Specification for Ordinary Portland Cement–Grade 33.*

[2] IS 455–1989: *Specification for Portland Slag Cement.*

[3] IS 8112–1989: *Specification for Grade 43 Ordinary Portland Cement.*

[4] IS 12269–1987: *Specification for Grade 53 Ordinary Portland Cement.*

[5] IS 12330–1988: *Specification for Sulphate-resisting Portland Cement.*

[6] IS 1489–1991: *Specification for Portland Pozzolana Cement Part 1 Flyash-based, Part 2 Calcined Clay-based.*

[7] IS 4031–1996: *Method of Physical Tests for Hydraulic Cements – Parts 1 to 15. Sieve Analysis, Specific Surface, Soundness, Standard Consistency, Setting Time, Compressive Strength, Transverse and Compressive Strength, Heat of Hydration, Drying Shrinkage and Density, Air content, Water retentivity, False set fineness by wet sieving.*

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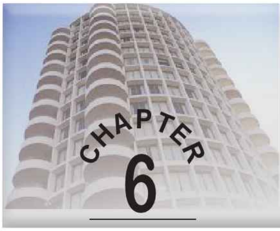

CHAPTER 6

Pozzolanas

6.1 GENERAL

Pozzolanas are materials containing reactive silica (in amorphous form) which in themselves possess little or no cementitious value but which combines with lime in finely divided form in the presence of water to produce cementing compounds. The combination is a chemical action, similar to that taking place in the setting of cement. Pozzolans enable the free lime in cement to set by means other than by carbonation (without the presence of air) and add to the strength of cement. The term pozzolana was given to such material in honour of the place Puzzolini in Italy, where it was recently found that Romans had built hydraulic structures by mixing lime and the local volcanic ash, thus producing hydraulic lime which can set under water. Nowadays, pozzolanas are used as follows.

(a) In finely ground form *as a mixture in ordinary portland* cement, up to 35 per cent, to make Pozzolana Portland Cement (PPC). For this purpose it must be ground finer than cement.

(b) The material is added separately as *a replacement,* or admixture up to 20 per cent of fine aggregate in lime and cement mortar to improve grading and to use the pozzolanic properties. The fineness of the material is not as important as for use as pozzolana.

(c) Mixed as a fine powder to fat lime to produce *hydraulic lime from fat lime*.

The difference between the first concept of strength addition and second concept of replacement of fine materials in concrete should be understood clearly.

6.2 POZZOLANIC MATERIALS

In general, pozzolanic materials are classified into two groups namely (a) natural pozzolanas such as volcanic ash and (b) artificial pozzolanas like flyash. In India, we do not have many deposits of natural pozzolanas. The two most commonly used pozzolanic materials in India are *surki and flyash*. Other pozzolanic materials used are rice husk ash and blast furnace slag. The most important requirement of pozzolana for pozzolanic portland cement is that the added material should be present in the cement *in a very fine powder form and intimately mixed* in the factory. When used with lime, to make it hydraulic it is generally added at the site during the time of mixing. A brief description of the principal pozzolanic materials is given below:

1. ***Surki.*** Surki was once very popular in use and readily available in India. Nowadays, it is not readily available. Ordinary surki is made by grinding well-burnt (but not over- or under- burnt) broken brickbats, tiles, etc. Reactive surki, which has superior lime combining properties is obtained by calcining selected clays within optimum temperature range and grinding the product into a fineness of 90% passing through IS sieve No. 15 (150 mesh). Due to increased cost of grinding and availability of very large quantities of flyash at no cost there is now no production of surki in India.
2. ***Flyash.*** Flyash is a finely divided ash resulting from the burning of pulverized coal or lignite in boilers. The flyash obtained from lignite is considered superior to that obtained from coal because of its higher lime content. Flyash is a waste product, and today, it is easily available in all parts of India. The fineness and presence of objectionable ash should be checked in the field by mixing the flyash in a bucket half full of water and passing the resulting slurry through an IS sieve 150 microns. No residue shall be left behind on the sieve in the case of a good sample of flyash.
3. ***Ground blast furnace slag.*** From slow cooling of the slag obtained from blast furnace, we get crystalline materials which can be crushed and used as aggregates. Rapid cooling of slag produces amorphous glassy pellets with about 35 per cent silica which when ground to fine powder can form a pozzolanic material. It can chemically react with the free lime to produce cementing materials.
4. ***Rice husk ash.*** If rice husk is burnt, the resulting ash contains about 80 per cent silica varying with the type of rice husk. If it is burnt with free access to atmosphere, then the resulting silica is crystalline. However, if it is burnt under controlled condition with limited access to air to temperature of about 700°C for 2 to 3 hours, then the silica produced is non-crystalline (amorphous). Such burnt rice husk ash has very good pozzolanic properties. Rice husk ash with not more than 20% cement produces an acid-resisting cement. For good performance, the mixture should be ground for at least about an hour in a ball mill.

6.3 ADVANTAGES OF ADDITION OF POZZOLANAS

The main advantages of adding pozzolanas to cement and fat lime are the following.

1. ***Economy.*** Materials like flyash are waste products and are cheap. Hence, as much as 10 to 25 per cent of costly cement can be replaced by pozzolanas.
2. ***Reduces permeability of concrete.*** As these materials are very fine when mixed to make concrete, they fill up the pores of concrete fully. Moreover, all the free lime in cement reacts with these materials, thus forming a dense mass. In this case it is considered as an admixture.
3. ***Addition to fat lime.*** Addition of pozzolanas to lime allows the formation of cementing compounds by chemical action. This can convert fat lime into a hydraulic lime. Traditionally, surki was used in India to convert fat lime into hydraulic lime and this was used for construction of hydraulic works.

6.4 STORING OF POZZOLANAS

Surki and flyash, if stored at site, should be protected from dirt, rain and dampness by means of adequate coverings. Like cement, it is stored best in bags. The reactivity is very much reduced if the material gets moist or becomes wet before it is used on the works.

6.5 REQUIRED CHEMICAL AND PHYSICAL CHARACTERISTICS OF FLYASH

When crushed or powdered bituminous coal or lignite is burnt in boilers of industrial plants like powerhouses, finely divided ash escape with the flue gases. 80% of the total ash is finely divided and by suitable technologies there are collected. This material is known as flyash. It is also known as pulverised fuel ash. The ash collected from bottom of boilers is known as bottom ash. Large quantities of flyash are produced in India as a waste material and the Indian government has given special incentives for its utilisation As flyash contains reactive silica it can be used as a pozzolana. It can also be used as an admixture to concrete. This there are three ways it is used namely

(i) Mixed with clinker and ground to produce PPC
(ii) Mixed with cement as a pozzolana to produce PPC.
(iii) Added to mortar and concrete as an admixture.

IS 3812 deals with use of pulverised fuel ash. It was published in 1981 in 3 parts but in 2003 it has been published as second revision in 2 parts. Part 1 deals with the specification of fly ash for use as a pozzolana and Part 2 deals with the speficication for its use as an admixture to cement mortar and concrete. There are many chemical and physical requirements specified in this IS Code. The main physical requirements the two uses are the following.

1. ***Fineness.*** The minimum specific surface by Blane's apparatus should be 320 m^2/kg for use as a pozzolana and 200 m^2/kg for an admixture compared to the value of 225 m^2/kg required for cement.
2. ***Particle size.*** The maximum percentage of particles retained on 45 micron IS sieve (wet sieving) should be 34 for use as a pozzolana and 50 for use as an admixture.
3. ***Lime reactivity.*** Minimum average compression strength in 10 days on three 7 cm mortar cubes, made with one part of hydrated lime, two parts of flyash and three parts of standard sand by weight, should not be less than 4.5 N/mm^2 for use of flyash as a pozzolana.
4. ***Soundness by autoclave test.*** On testing a mixture of 4 parts of ordinary Portland cement and one part of flyash by weight, the increase in volume should not be more than 0.8 per cent in both cases.
5. ***Compressive strength with cements.*** With a mixture of ordinary portland cement and flyash, the compressive strength should not be less than 80 per cent of the strength of corresponding plain cement mortar cubes.

SUMMARY

Flyash as a pozzolanic material is being used more and more throughout the world. It makes the cement cheaper in cost and the concrete more impermeable by reacting with the free lime present in cement. It also enables us to put industrial waste to good use. However, we should remember that flyash concrete requires very careful curing and wherever it is used, arrangements for proper curing must be insisted on.

REVIEW QUESTIONS

1. Explain the advantages of addition of pozzolanas to cement and also to lime for using in building construction.
2. Explain how addition of pozzolanas can convert fat lime into hydraulic lime.
3. Give brief account of the different pozzolanic materials available for use in India.
4. Write short notes on:
   (a) Flyash
   (b) Surki
   (c) Blast furnace slag
   (d) Rice husk ash
   (e) Portland pozzolana cement (PPC)
5. What are the requirements of flyash when (a) it is to be mixed with cement to niake PPC (b) it is to be used as a replacement of fine aggregate.
6. As the densities of cement and flyash particles are very different, can you divise a test to determine the percentage of flysh (or other lighter material) present in the cement supplied?

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[3] IS 3812–2003 Pulverised Fuel Ash Specification: Part 1—For use as pozzolanas in cement (cement mortar and concrete). Part 2—For use as admixture in cement mortar and concrete.

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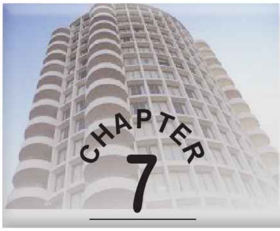


CHAPTER 7

Sand (Fine Aggregate)

7.1 GENERAL

Sand is essentially quartz whereas clay is made of many other chemically active minerals like illite, kiolinite, etc. Sand between 4.75 mm (about 5 mm) and 0.150 mm in size is called as fine aggregate. It is used for making concrete, mortars and plasters. It is also used for filling under floor, basements. For economy in construction, as far as possible local sand, fit for the particular use, should be used. Otherwise, transport expense will be a major part of the cost of the sand. Natural sand is available from local river beds or pits. An examination should be made on the fineness of the available sands and depending on its fineness, it should then be planned to be used for the different items of the construction. Due to increased construction activity, natural sand is becoming more difficult to get and in cost also. Hence, search of alternative materials like crushed rock and flyash for use in construction is now a popular subject for research. In this chapter, we will briefly deal with the uses of sand in building construction and the tests that can be done to determine its suitability for different uses.

7.2 SOURCES OF SAND

Sand is sometimes classified according to the source of supply such as:

1. ***Pit sand.*** This type of sand is obtained from old stream beds. It is sharp and generally coarse.
2. ***River sand.*** This is obtained from large rivers. It is usually fine in size. While taking it from rivers, care should be taken so that there is no clay mixed with the sand.
3. ***Stream sand.*** It is obtained from small streams near hills that may dry out in summer. This type of sand is generally coarse in size.
4. ***Crushed stone sand.*** It is obtained from the screenings left from crushed stone. It usually contains a high percentage of dust and clay. Nowadays, because of the difficulty in getting natural sand, special crushers are being introduced in India for making fine aggregate from rocks.
5. ***Sea sand.*** It is obtained from beaches. It is generally good for most of the works, except reinforced concrete works, if they are free from detrimental salts. Even though many specifications do not allow this type of sand to be used in construction, one may be forced to use them in works in small islands and in the faraway beaches. They can then be, if necessary, washed in fresh water and used.

7.3 IMPURITIES IN SAND

Clay, silt, salts, mica and organic matter are the main impurities in sands. Sand should also be free from shells, wood particles, etc. It is sometimes specified that the sum of all impurities should not exceed 5 per cent. Presence of large percentage of mica reduces the strength of mortar or concrete made from such sand. Generally, a maximum of 8 per cent silt and 2 to 3 per cent of mica are allowed in sand for mortar and concrete.

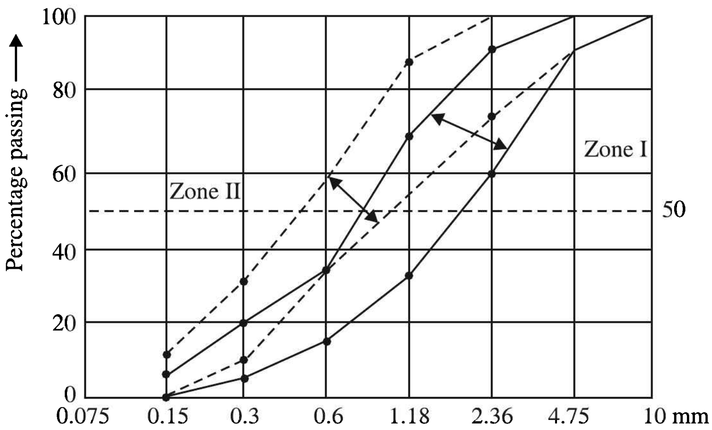
7.4 CLASSIFICATION OF SAND FOR MAKING CONCRETE

Depending on the percentage of the various sizes of sand present in a sample, sand for making concrete is grouped into five zones—Zone I to Zone V (very coarse to very very fine as given in Table 7.1). This table can also be represented as grading curves as shown in Figure 7.1.

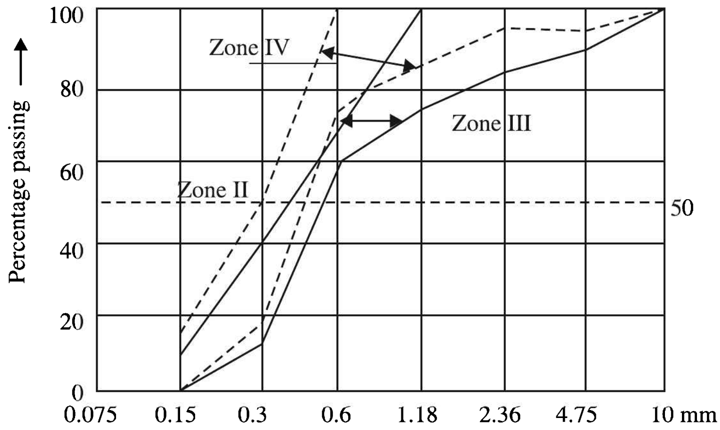
Table 7.1 Grading of fine aggregates for concrete—Zones I to V (I.S. 383–1970)

I.S. Sieve No.		7		14	25	52	100
I.S. Sieve size		Millimetre				Microns	
	10	4.75	2.36	1.18	600	300	150
Very coarse (Zone I)	100	90–100	60–95	30–70	15–34	5–20	0–10
Coarse (Zone II)	100	90–100	75–100	55–90	35–59	8–30	0–10
Fine (Zone III)	100	90–100	85–100	75–100	60–79	12–40	0–10
Very fine (Zone IV)	100	95–100	95–100	90–100	80–100	15–50	0–15
Zone V	–	–	100	100	85–100	65–95	0–60

Most of the particles in sand pass 4.75 mm or say 5 mm. As can be seen in Figure 7.1, the main criterion for division into coarse and fine can be taken as 0.6 mm in size. If major part is above 0.6 mm in size, then it is called coarse sand. If major part is below 0.6 mm in size, then we can call it fine sand. (Particles that can not been by naked eye is silt).



(a)



(b)

Figure 7.1 Grading limits for sand (a) and (b) Zones I to IV (coarser to finer).

(In soil mechanics also, we consider sands as those particles which pass through 4.75 mm and those which retain on 0.075 mm. Sand is further divided in soil mechanics by examining the particle sizes as follows.

Coarse sand: 4.5 mm to 2.0 mm

Medium sand: 2.0 mm to 0.425 mm

Fine sand: 0.425 mm to 0.075 mm

A given specimen of sand is to be classified in visual identification as coarse, medium or fine depending on whether the major part of its particles is coarse, medium or fine (Figure 7.2).

SAND		
Fine	Medium	Coarse

0.075 0.425 2.0 4.5 mm

Figure 7.2 Classification of sand.

7.5 SAND FOR CONCRETE WORK

Very fine sands (Zone IV and V sands of Table 7.1) are not recommended for structural concrete unless field tests show that they can be used. Very coarse sand shows difficulties in surface finishing of concrete but provides good strength. Fine sand provides more cohesion than coarse sand and hence, less sand will be needed if fine sand is used. While making concrete, coarse aggregates from rocks (of irregular size) will need more sand than rounded coarse aggregates such as river gravel. In most of the cases, the concrete mix can be designed to fit the available sand and coarse aggregates.

7.6 SAND FOR MORTARS AND PLASTERS

For making mortars and plasters for buildings, in most of the situations, one has to make use of the sand available near the site of the work. In general, sharp sand gives higher mortar strength, but is unsuitable for bricklaying as it lacks plasticity or workability. Mortar made of very coarse sand does not adhere easily to the bricks during bricklaying. This factor should be given special attention in mountain areas, where only coarse sand may be available in plenty. Soft sand is the ideal material for making mortar and plaster for brickwork. Sharp sand mixed with soft sand can also be used for plastering or as mortar. If only coarse sand is available, it is recommended to sieve the sand through a suitable sieve and use only the fine portion for the work.

Generally, it is considered that the sand used for mortar for brickwork should pass through a sieve of 8 meshes per inch (3.2 mm) and the sand for plastering and pointing must pass through a sieve of 12 meshes to the inch (2 mm) even though MDSS used to recommend it to pass through a sieve with 18 meshes to an inch. Another recommendation for sand used for plaster and mortar work is that the percentage of material that pass through a 600 micron sieve should be 40 to 100 per cent for mortars, and 80 to 100 percent for plasters thus enabling a wide variety of sand to be used for this purpose. Thus, we should remember that even though coarse sand can be used for mortar for brickwork, for plastering and rendering of brickwork, we require finer sand. The recommended grading of sand for masonry mortars and plasters is given in Table 7.2.

Table 7.2 Grading of Sand for Masonry Mortars and Plasters

I.S. Sieve	Mortars I.S. 2116–1980 % passing	Plasters I.S. 1542–1977 % passing
4.75 mm	100	100
2.36 mm	90–100	95–100
1.18 mm	70–100	90–100
600 micron	40–100	80–100
300 micron	5–70	20–65
150 micron	0–15	0–50

7.7 SAND FOR FILLING

Sand is also used in building construction for filling underground floors and also filling behind retaining walls, etc. In each situation, it should satisfy the specific requirements for its use. Sand used for filling underground floors has to reduce the capillary suction by which water will travel from foundation soil to the floor. This will require coarse sand with large voids between the grains. On the other hand, for sand required for filling behind retaining walls, the only requirement is that it should be free draining and non-expansive. Most of the sands are not expansive as they get saturated at low water content. Thus, most of the free draining sands are suitable for general filling purposes.

7.8 BULKING AND TEST FOR BULKING OF SAND

Compared to its dry or completely saturated volume, moist fine aggregate tends to increase in volume *on rehandling* due to capillary effect. The capillary action between sand particles does not allow the particles to come closer to each other. This is called *bulking of sand* and the amount of bulking or increase in volume depends on the moisture content of the sand. In completely dry or wet state, there is no capillary action and hence, there will be no bulking when the sand is dry or completely saturated. Hence, a correction must be made for the volume of the sand when it is measured by volume in the moist state for use in making concrete. For a moisture content of 5 to 8 per cent, the bulking can be as much as 20 to 40 per cent depending on the sand. Bulking is not considered when sand is measured by weight.

Bulking that can take place for a given sand can be easily determined by rehandling it. Pour enough rehandled sand in a 250 cc measuring cylinder. By consolidating it by simple shaking, only, make it come a level. Let the height be h_1. Pour water to the sand and stir it well to saturate the sand till the level of water is above the sand. The decreased in volume is noted. Let its height be h_2. This decrease in volume expressed as a percentage of the real volume of the sand is known as percentage of bulking.

$$\text{Percentage of bulking} = 100 \times (h_1 - h_2)/h_2$$

7.9 MANUFACTURING OF SAND BY ROCK CRUSHING

We are nowadays forced to replace fully or partially natural sand by crushed sand. Severe restrictions are being imposed by many states in India in quarrying sand from river beds for the following reason. By mining sand from river bed, we lower the ground water level in the river in summer when there is no flow in the river. This, in turn, will lower the ground water level in all the neighbourhood. Hence, in many rivers, nowadays, taking of sand in dry season is restricted. Hence, in future, it will be necessary to plan to use fine aggregate obtained by crushing rocks or use a mixture of natural sand and crushed rock aggregates for making concrete. The main objection of crushed rock fine aggregates is that these aggregates are flaky and badly-graded whereas natural sand is well rounded and well graded. The latter requires less water for the same workability and thus, gives better concrete. However, with the introduction of better crushers which tend to give better-shaped crushed fine aggregates, there will be more and more use of crushed rock fine aggregate material in India. Crushed fine aggregates can also be made to give better concrete than concrete made from river sand by proper design of mixes. The harshness of these mixes can be removed by concrete additives. Many ready-mix concrete companies have already started this practice. The Pune-Mumbai express highway was a project where there was difficulty in procurement of natural sand. This made the construction company to use crushed fine aggregate for making approximately 20 lakh cubic metres of concrete necessary for the construction.

7.10 TESTS FOR QUALITY OF SAND

The principal tests for sand are:

1. Test for grading
2. Test for organic impurities
3. Test for clay and silt content

Additional tests:

4. Test for specific gravity and bulk density
5. Compacted and loose bulk density of sand (fine aggregate)

1. ***Test for grading.*** This test is made by sieve analysis using sieves given in Table 7.1 and 7.2. It will give us the data regarding the zone into which the sand can be placed.

The various zones are classified as very coarse, coarse, fine or very fine as shown in Table 7.1 and Figure 7.1.

2. ***Test for organic impurities.*** This is an important test for dirty sands. A 350-ml graduated glass bottle is filled to 75 ml with 3% solution of sodium hydroxide. Sand is added to this solution till 125 ml mark is reached, and then, it is made up to 200 cc by adding more of the above solution. The bottle is stoppered, shaken vigorously to enable the organic matter to be digested and allowed to stand for 24 hours. The colour of the liquid above the sand will indicate whether or not there is dangerous amount of organic matter. A colourless or straw colour, which indicates some organic matter, is not objectionable. On the other hand, a dark colour indicates objectionable amount of organic substances. In such cases, the sand should be washed before it is used and a retest is done to test its washing.

   The colour of the liquid can be compared to the colour of a solution made as follows. Add 2.5 cc of 2% solution, of tannic acid in 10% alcohol to 97.5 cc of 3% sodium hydroxide solution thus making 100 cc. This is placed in a 350 cc container, stoppered, shaken vigorously and allowed to stand 24 hours. The colours of a usable sand and this solution should be comparable and not darker. Alternately, the colour of a solution with sand may be compared with available standard charts.

3. ***Test for clay and silt content.*** A sedimentation test as carried out in Soil Mechanics can be carried out for this purpose. The test consists of taking a dry sample of 300 gm of air passing 4.75 mm I.S. sieve and placed in 300 ml of dilute sodium oxalate (as a dispensing agent for silt and clay) made with 0.8 gm of sodium oxalate per litre. The jar is then shaken thoroughly for 15 minutes. The silt and clay will go into suspension. The suspension is then poured into a 1000 ml measuring cylinder. The residue is washed again with the sodium oxalate solution, the washing being poured into the cylinder. After all the clay and silt has been washed out of the sand, the volume in the cylinder is made up to 1000 cc The contents are once again shaked well and a sample is drawn immediately by a pipette and dried to find the silt and clay content.

$$\text{Silt and clay content} = \left(\frac{100}{W_1}\right)\left(\frac{W_2}{V} \times 1000 - 0.8\right)$$

where

W_1 = Dry weight of total sample

W_2 = Weight of fines in the pipette sample

V = Volume of sample taken in pipette and

Weight in 0.8 gm of sodium oxalate in solution.

Alternate field test. The following simple test as given in CPWD specification 77 is good enough for all purposes.

The sand should not contain more than 8 per cent of silt as determined by the following field test. A sample of sand to be tested is placed without drying in a 200 cc measuring cylinder, so that the sand is up to the 100 cc mark. Add clean water up to 150 cc mark. Dissolve one spoon of common salt in half litre of water thoroughly and add this to the measuring cylinder. The mixture is then shaken vigorously, the last few shakes being in sidewise direction. Allow the solids to settle down for a period of three hours.

First the sand settles and then silt and clay over it. The height of the silt visible as settled layer above the sand is expressed as a percentage of the height of the sand below the silt content.

SUMMARY

It is necessary to use the sand available near the site for the building works. In the near future, we have to seek for alternative materials as the available deposits of sand in natural deposits and rivers are getting depleted. The use of crushed sand produced by special crushers in being used more and more for concrete making. Many readymixed concrete plants are experimenting on such replacement at least in part.

REVIEW QUESTIONS

1. What is meant by sand, silt and clay? How do you roughly classify sand into fine sand and coarse sand? What is the IS classifications of sand for concrete making?
2. What type of sand will one use for (a) concrete work, (b) mortar work, (c) plaster work.
3. What are the three important simple tests that you will conduct on sand to find its suitability in civil engineering construction?
4. What is the dividing size between fine aggregate (sand) and coarse aggregate in making of concrete? When do you call sand coarse or fine in design of concrete mixes?
5. Explain the term "bulking of sand". Describe the field test to determine it. Indicate how it is important in controlling field concreting.
6. What is filling sand? What are the qualities that you look in sand used for filling under basement and behind a retaining wall.
7. As river sand is becoming more costly and exhaustible, what steps would you suggest for replacing it for civil engineering construction.
8. Why does government put restrictions in mining sand from river beds in summer?
9. Explain how we can replace natural sand by crushed sand for making concrete.

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[3] IS 1542–1992: *Specification for Sand for Plaster.*

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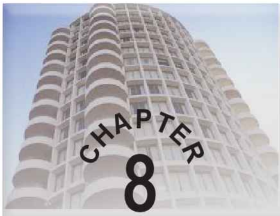


CHAPTER 8 Coarse Aggregate

8.1 GENERAL

Coarse aggregates are used for making concrete. They may be in the form of irregular broken stone or naturally-occurring rounded gravel. Materials which are large to be retained on 4.7 mm sieve size (say 5 mm for convenience) are called coarse aggregates. Its maximum size can be up to 63 mm. As we have already seen, materials which pass 5 mm sieve are called fine aggregates (sand). In this chapter, we will examine the requirements for grading and the tests prescribed for coarse aggregates for making concrete.

8.2 COARSE AGGREGATES

Broken bricks are also used for making brick jelly concrete. But coarse aggregates for *structural concrete* consist of *broken stones of hard rock like granite and lime stone (angular aggregater) or river gravels* (*rounded aggregates*). They should be clean and if dirty, should be washed well before using. Coarse aggregate is specified by its maximum size. Thus, a 40 mm aggregate will pass through a 40 mm ring. Also, for a specified size not more than 60 per cent and less than 30 per cent should pass through a sieve half the maximum size. The CPWD requirements for single sized upgraded coarse aggregates are given in Table 8.1.

Table 8.1 Single-size Aggregate (Ungraded)

I.S. sieve size mm	Percentage passing for nominal size of aggregate in mm					
	63	40*	20	16	12.5	10
80	100					
63	85 to 100	100				
40	0 to 30	85 to 100	100			
20	0 to 5	0 to 20	85 to 100	100		
16		–	–	85 to 100	100	
12.5		–	–	–	85 to 100	100
10.0		0–5	0 to 20	0 to 30	0 to 45	85 to 100
4.75			0 to 5	0 to 5	0 to 10	0 to 20

**Example:* 40 mm nominal size has 100 per cent passing a sieve size 63 mm, 85 to 100 per cent passing 40 mm sieve, 0 to 20 per cent passing 20 mm sieve and 0 to 5 per cent passing 10 mm sieve.

Note: In coarse aggregates, foreign materials such as coal, lignite, clay lumps and soft fragments shall not exceed 5 per cent of its weight.

Coarse aggregates are generally produced from large stones (obtained by blasting in stone quarries) by breaking them by hand or by crushers. Hand-broken aggregates usually consist of only single size stones. Machine-crushed stones consist of stones of various sizes, but, generally, they are first separated into stones of different sizes by passing them through different sieves after crushing. To produce graded aggregates, which are necessary for high class concrete, they are again mixed in specified proportions. These topics come under the special subject concrete technology. The usual maximum sizes of aggregates that are specified for different works are given in Table 8.2.

Table 8.2 Maximum Size of Aggregate for Various Works

Type of work	Maximum size specified
Non-reinforced work	40 to 75 mm (1.5 to 3 inch)
R.C. foundation work	40 mm (1.5 inch)
R.C. work (beams, columns, slabs in buildings)	20 mm (3/4 inch)
Shell roof and thin members	10 mm (3/8 inch)

Note: In R.C. work the maximum size of the aggregate is governed by the rule that it should not exceed “minimum spacing of steel minus 5 mm.” For non-structural mass concrete of low strength, broken bricks, clinker, foamed slag, etc., may be also used as coarse aggregates.

8.3 STORING AND HANDLING OF AGGREGATES

Aggregates should be stored and handled carefully, so that they remain free from contamination from dirt. They should also not be segregated and their moisture content should remain approximately constant. Before the aggregate is received at the site, a clean dry and hard patch of ground shall be selected, keeping in view the position of the mixer and the convenience in handling. If good ground is not available, then an artificial platform shall be prepared out of planks, galvanized iron sheets, bricks or lean concrete. Fine aggregates as well as different sizes of coarse aggregates must be stored in separate heaps.

To prevent segregation, which is very important, successive consignments should not be dropped on the older piles to form a pyramid. Aggregates must be placed in layers, each layer not thicker than a lorry load, care being taken not to drop the aggregates from a height. Otherwise, segregation of sizes will take place.

To avoid excessive variation in moisture content, each pile of aggregates must be kept in a large area but low in height (not exceeding 1 m). They shall be allowed to stand for at least 24 hours before use. Conical heaps must be avoided as they assist segregation.

8.4 SAMPLING AND TESTING OF AGGREGATES

The routine and other tests usually prescribed on coarse aggregates are as follows:

1. ***Routine tests***
   (a) Particle size, (grading) shape and *flakiness* (3 tests)
   (b) Organic impurities

(c) Moisture content
(d) Ten percent fines value
(e) Water absorption and specific gravity

2. **Other special tests**
(a) Aggregate crushing value
(b) Aggregate impact value
(c) Aggregate abrasion value
(d) Bulk density and void ratio

8.5 DESCRIPTION OF ROUTINE TESTS

Of the above tests, only the first five tests are specified as mandatory and important in many specifications like CPWD specification 77. These are briefly described below:

8.5.1 Particle Size, Shape and Flakiness (IS 2386–1963: Part I)

1. ***Test for particle size.*** This is carried out in the field by sieve analysis. The results are plotted as a grading curve as already shown for sand in Fig. 7.1.

2. ***Tests for shape.*** Aggregates are classified according to their shape as follows:
(a) Rounded
(b) Irregular or partly-rounded
(c) Angular
(d) Flaky

The shape of aggregates becomes important in case of high strength (high performance) concrete where very low water-cement ratios are to be used. In such cases, cubical-shaped aggregates are preferred for better workability. Improved makes of crushers such as Hydrocone crushers, Barma rock or Rock VSI crushers, give better products than ordinary jaw crushers. The laboratory test for shape is known as test for flakiness or elongation index. The apparating used is shown in Figure 8.1.

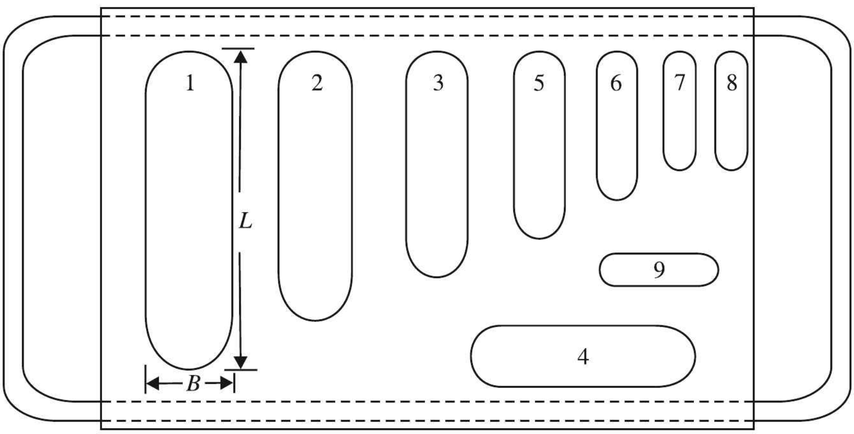


Figure 8.1 Apparatus to test flakiness of coarse aggregates.

3. ***Test for elongation index (flakiness).*** The flakiness or elongation index of an aggregate is defined as the percentage weight of particles in the given aggregate which has its length greater than 1.8 times and its least dimension (thickness) is less than 3/5 (or 0.6) times its mean dimension. A length gauge with holes of various sizes as specified is available as a standard piece of laboratory equipment as shown in Figure 8.1. This test is not used for aggregate sizes smaller than 6.3 mm.

For the test, sufficient quantity of sample should be taken so that the minimum number of 200 pieces of any standard size fraction is to be tested. The following is the procedure of the test.

1. Take sufficient quantity of the aggregate and sieve it through the different standard sizes of sieve shown in Table 8.3 into fractions. Each fraction should be tested for flakiness.
2. Each fraction is gauged in turns through the hole of dimension of thickness 0.6 times and of length 1.8 times the mean size of the aggregate as shown in Table 8.3.
3. The total amount passing through the various gauges is weighed to an accuracy of 0.1% of the weight of the sample.
4. *Flakiness index* is the total weight of the material passing through the gauges of various thickness expressed as a percentage of the total weight of the sample taken.

British specifications limit this index to 50 for natural aggregate and 40 for crushed coarse aggregate. For wearing surfaces like roadwork, we may adopt a lower value.

Table 8.3 Mean Sieve Sizes and Size of Gauges (I.S. 2386, Part I–1963)

Sieve sizes (mm)		Mean size (mm)	(B × L) Dimensions of gauge (mm)	Figure 8.1
Passing	Retained			
63	50	56.5	33.9 × 100	1
50	40	45*	27.0 × 81.0	2
40	25	32.5	19.5 × 58.5	3
31.5	25	28.25	16.95 × 50.85	4
25	20	22.5	13.5 × 40.5	5
20	16	18.0	10.8 × 32.4	6
16	12.5	14.25	8.55 × 25.6	7
12.5	10.0	11.25	6.75 × 20.2	8
10.0	6.3	8.15	4.89 × 14.7	9

**Example:* For mean size 45 mm, the gauge size is (0.6 × 45) and (1.8 × 45) = 27 × 81 mm

8.5.2 Test for Organic Impurities, Clay Content and Percentage Fines

The same test as described for fine aggregate (sand) can be used for coarse aggregate also. The clay content and percentage fines can be found by immersing the aggregate in water and examining the suspended particles in the water.

8.5.3 Test for Moisture Content

The easy test is the drying method in an oven or heating in an open pan in the field. It can also be carried out by pouring an inflammable liquid like methylated spirit and igniting it to evaporate the water.

8.5.4 Test for Load for 10% Fineness Value or Crushing Value

(Sample preparations for this test and also for the test called aggregate crushing test described later are similar). About 6.5 kg material consisting of material passing 12.5 mm and retained on 10 mm sieve is taken and compacted in the standard cylinder used for this test in three layers—each layer being compacted 25 times with a tamping rod. The top layer is levelled off. The weight of the sample is recorded. The same weight should be taken for subsequent tests also. The apparatus used is shown in Figure 8.2.

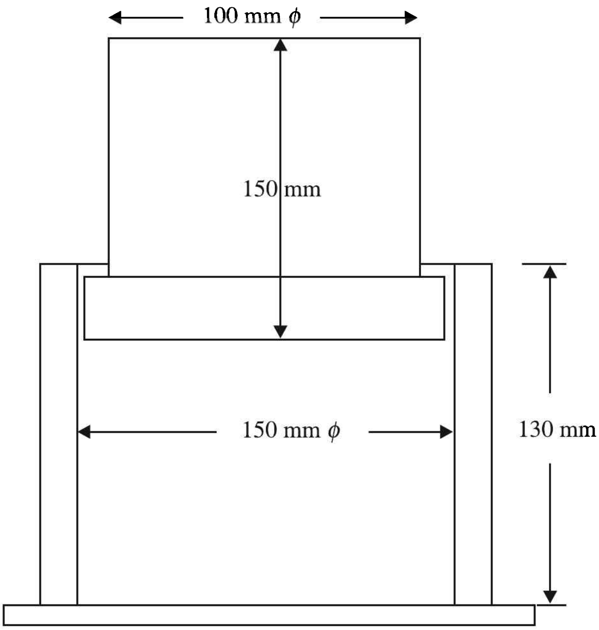


Figure 8.2 Apparatus for ten percent fines value for coarse aggregates.

On the cylinder with the base plate, the plunger is placed and the unit is set up in a compression testing machine. The load is applied gradually at a uniform rate so that the plunger penetration is as given below in 10 minutes:

About 15 mm for rounded or partially-rounded aggregate like natural gravel samples; 20 mm for normal crushed stones and 24.0 mm for honeycombed aggregates like shale and slag.

After reaching the necessary penetration the load is released and the material is sieved through 2.36 mm I.S. sieve. The percentage of the fines passing the above sieve is expressed as a percentage of the weight of the test sample. This should be on the range of 7.5 to 12.6% (i.e. about 10%). Repeat the test till we find the load for the above result. Then load for 10% fines is calculated as follows.

$$\text{Load for 10\% fines} = \left(\frac{14}{y+4}\right)x$$

where

x = load in tonnes for causing 7.5 to 12.6% fines

y = mean of the percentage of fines from two tests at x tonnes load

The value is reported in the nearest 0.5 tonnes and the recommended values are as follows:

(a) For normal concrete, not less than 5 tonnes
(b) For wearing surface for road pavements, not less than 10 tonnes
(c) For ganolithic concrete in buildings, not less than 15 tonnes

8.5.5 Aggregate Crushing Value

In this test, we find the percentage of fines at a specified load of 40 tonnes. The preparation for this test is the same as that for 10 per cent fines. In this test, after the specimen is set in the compression machine, the plunger is loaded to *40 tonnes in 10 minutes*. The load is released and the material is sieved through 2.36 mm sieve (same sieve as used in 10% fine test) to obtain the aggregate crushing value or the percentage fines. It is usually recommended as 45 per cent for aggregates used for concrete other than that used for wearing surfaces. For concrete for wearing purposes, it should not exceed 30 per cent. Generally, it ranges from 18 to 27% for Indian aggregates.

8.5.6 Test for Water Absorption and Specific Gravity (IS 2386–1963 : Part III)

A sample of aggregates not less than 2 kg is washed and immersed in water for 24 hours and its immersed weight in water is found (A). It is taken out of the water and the saturated surface dry sample is weighed in air (B). It is then over-dried and weighed (C).

$$\text{Specific gravity} = \frac{C}{B-A} \quad \text{and} \quad \text{Percent water absorption} = \frac{B-C}{C}\times 100$$

8.5.7 Aggregate Impact Test

This test is for aggregates in concrete that undergoes impact as in runways in airports. Materials passing through 12.5 mm and retained as 10 mm are filled in the standard cylinder in three layers, each layer tamped with 25 strokes of an iron rod. A hammer weighing 14 kg is dropped from a height of 380 mm 15 times and the resulting material is sieved through a 2.36 mm I.S. sieve. The percentage fine is the aggregate impact test value. It should not be more than 45% for aggregates for concrete for ordinary use and not more than 30% for aggregates for concrete for runways and pavements. For Indian aggregates, it ranges from 15 to 30%.

8.5.8 Aggregate Abrasion Value (Attrition Test)

This test is for the stones used in road construction. We use the Deval's abrasion testing machine or preferably the Los Angeles abrasion machine for this purpose. In the latter test, a sample of specified grading which varies with the maximum size of aggregate to be tested is placed in the machine with steel or cast iron spheres of 48 mm diameter and 390 to 445 gm weight. The machine is rotated for specified revolutions depending on the grading (500 to 1000 revolutions). The resulting material is sieved through 1.7 mm sieve. The percentage of wear is called the Los Angeles aggregate abrasion value. It should not be more than 16 per cent for a good aggregate.

8.5.9 Bulk Density and Void Ratio

Bulk density is determined by packing the aggregate into a specified container of known volume and determining the weight of the aggregates packed.

$$\frac{\text{Weight}}{\text{Volume}} = \gamma = \text{bulk density}$$

$$\text{Void ratio} = \frac{G_s - \gamma}{\gamma}$$

where G_s = Specific gravity of aggregate

8.5.10 Aggregate Crushing Strength

This test is performed on a core or cube obtained from the original rock. It gives a measure of the strength of the parent rock (see Section 1.5.1).

8.6 MEASURE OF STRENGTH OF AGGREGATES

As discussed earlier, the three tests that deal with the strength of aggregates are

(a) Ten percent fineness value
(b) Aggregate crushing value
(c) Aggregate crushing strength

Of these, the ten per cent fineness value is considered a good test for weak aggregates while the crushing value is considered good for general aggregates. As already stated, crushing strength gives only the strength of the parent rock.

8.7 ALKALI AGGREGATE REACTION

It was as late as in 1940 that it was discovered by the American Bureau of Reclamation that some of the natural aggregates that contain reactive silica (like traps, andesites, rhyolite, some types of limestones, sandstones and natural gravels) react with the alkali of the cement and produce compounds that cause expansion and deterioration of concrete. Such concrete can become unserviceable even in one year's time. Aggregates from such sources should be *tested for reactive silica* by special tests for its suitability for making concrete.

SUMMARY

Very good coarse aggregates are necessary for durable concrete construction in buildings and in road works. IS 383 and IS 2386 deal with the requirements of coarse aggregates for concrete.

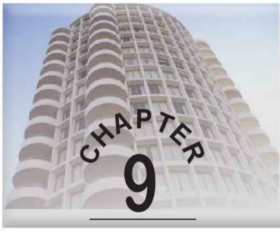
REVIEW QUESTIONS

1. (a) What is meant by coarse aggregates
   (b) What are the maximum sizes of coarse aggregates used for the following types of work:
      (i) Mass concrete in foundation
      (ii) Columns, beams and slabs
      (iii) Thin members like shell roofs
   (c) What are the precautions to be taken in storing coarse aggregate at the site for construction work?
2. (a) What are the routine tests and special tests to be conducted on coarse aggregates for making in concrete?
   (b) Describe the test for flakiness of aggregates.
3. Write short notes on the following tests on coarse aggregates.
   (a) Ten percent fine value test.
   (b) Aggregate crushing value
   (c) Aggregate impact test value
   (d) Aggregate abrasion value
4. Describe the mandatory tests recommended to assess *the strength of coarse aggregates* for use in concrete.
5. (a) Where are the sources of angular coarse aggregate and rounded coarse aggregates?
   (b) What nominal size of aggregate is usually used for reinforced concrete in building works?

REFERENCES

[1] IS 383–1970*: Specification for Coarse and Fine Aggregates from Natural Sources for Concrete.*

[2] IS 2386–1963 *Parts 1 to 8: Methods of Tests for Aggregates for Concrete (Part 1: Particle size and shape, Part 2: Estimation of deleterious materials and organic impurities, Part 3: Specific gravity, density, voids, absorption and bulking. Part 4: Mechanical properties.)*



CHAPTER 9 Water

9.1 GENERAL

Water should be considered as an important material for construction, where it is mainly used with cement for making mortar, concrete, etc. and also for curing of cement works. Many concrete structures have deteriorated with time due to the presence of deleterious substance present in the water used for their construction or due to the presence of sulphates in the ground water. Presence of chloride in water used for making reinforced concretework leads to corrosion of steel. Exposure of concrete to sulphate waters causes deterioration of concrete in the foundation. Hence, pains should be taken during initial stages of construction to get the representative sample of available water at the site to be tested before it is used. The nature of groundwater available at a site will also vary with the seasons. In places near the sea, like Chennai in S. India, the concentration of salts in bore wells is the maximum during summer when construction activity is at its peak. Hence, suitability of available ground water at the dry season should be examined carefully for its suitability for construction. Water is also used for human consumption, but the standards laid down for water for construction is different from those for drinking purposes. It is also important to test whether or not the groundwater contains sulphates which are harmful to the concrete work like foundations made from ordinary cement. In this chapter, we will briefly examine how to test (a) water used for mixing concrete for R.C. construction and (b) the groundwater to check whether it is aggressive to concrete made from ordinary cement.

9.2 LIMITS OF DELETERIOUS MATERIALS ALLOWED IN WATER FOR CONSTRUCTION

Limits have been set on allowable acidity, alkalinity, and percentage of suspended and dissolved salts present in water used for making concrete and mortar. Guidance for examining the suitability of the available water for construction can be obtained from the following data specified in IS 456 (2000), Clause 5.4.3. The following are important factors to be considered.

1. The pH of water should generally be not less than 6. (Lesser values show that water is acidic.) Further tests for acidity and alkalinity are given by (a) and (b) below.

(a) ***Limit of acidity.*** To neutralize 100 cc sample of water (using phenolphthalein as indicator), not more than 5 cc of 0.02 Normal NaOH (caustic soda) solution should be required. This test ensures that the water is not acidic (Refer IS 3025 for details).

(b) ***Limit of alkalinity.*** To neutralize 100 cc of water (using mixed indicator), not more than 25 cc of 0.02 Normal, H_2SO_4 (sulphuric acid) should be required. This test ensures that the water is not alkaline.

(c) ***Percentage of solids.*** The limits specified by IS 456 (2000) for solids in *parts per million or mg/L* in water are the following.

1. Organic solids: 200 (0.02%) tested by (IS 3025 part 18)
2. Inorganic solids: 3000 (0.03%) tested by (IS 3025 part 18)
3. Sulphates as SO_3: 400 (0.04%) tested by (IS 3025 part 24)

Note: Even though seawater contains as much as 0.25% sulphates the presence of chlorides inhibit the action of sulphates.

4. Alkali chlorides (ASCL): 2000 (0.2%) for concrete not containing steel and 500 (0.05%) for R.C. work.
5. Suspended matter: 2000 (0.2%) tested by (IS 3025 part 17)

Note: In drinking water WHO allows dissolved solids only to the limit of 500 mg per litre (0.05%). Testing for pathogenic organisms is only to be carried out for potable (drinking) water.

9.3 USE OF BRACKISH OR SEAWATER FOR CONSTRUCTION (IS 456–2000 Clause 5.4.3)

Whenever unpotable water is to be used for general use in construction, special care should be exercised to test its suitability. Seawater or brackish water is not at all allowed to be used for making or curing *reinforced concrete work*. However, use of such water for plain or mass concrete or for making cement mortar is sometimes permitted when fresh water is difficult to be obtained at the site as in small islands. However, seawater should not be used with fat lime or for making lime mortar. In case of doubt, the suitability to use the available water with cement for mortar or plaster works other than for R.C. work can be ascertained by casting 15 cm concrete cubes with the proposed water and also with distilled water. The average 28 day strength with the given water should not be less than 90 per cent of the average strength of similar cubes prepared with distilled water.

9.4 ESTIMATION OF SULPHATES IN GROUNDWATER

Presence of sulphates in soil and in groundwater is *very injurious to concrete in foundations*. Presence of sulphates in sewage water also breaks up concrete. Special cements have to be used under such situations. IS 456 (2000), Table 4 gives us the precautions to be taken in construction. In this table, the sulphates are expressed as SO_3 as the effect of sulphates are usually judged by the *amount of soluble sulphates present as* SO_3.

The sulphates in soil are determined separately as total sulphates and soluble sulphates. For determination of total sulphates, we take an extract with hot dilute hydrochloric acid from the soil. For soluble sulphates, we take an extract with distilled water equal to twice the weight of the soil. Then, the sulphates are precipitated by $BaCl_2$ for estimation. The sulphates are estimated by titration with K_2CrO_4.

9.5 ESTIMATION OF SULPHATES IN MIXING WATER FOR CONCRETING

For reporting results of water analysis for concreting as in Table 9.1, we express sulphates as SO_4 as given in IS 3025. On the other hand, as given above, while testing the, ground water for estimating the exposure condition for choosing the type of cements to be used in construction, we express sulphates in terms of SO_3 as per IS 456 and B.S. According to ACI, it is also to be expressed in terms of SO_4

9.6 TEST REPORT FOR WATER FOR CONCRETING

A specimen of the test report for water to be used for concrete construction in buildings is shown in Table 9.1. The tests prescribed for water for human consumption are different and are dealt with in the subject Public Health Engineering.

Table 9.1 Specimen Test Report on Water for Construction (Concreting)

Data

Sample No: Job No.	Date
1. Clients name	
2. Address	
3. Sampling method	
4. Sample recd on	
5. Test start date	

Test Results

No.	Tests	Protocol	Result	Requirement/Limits (IS 456-2000)
1.	Chlorides (Cl)	IS:3025:Part32:1999		$\ngtr$ 2000 mg/L
2.	Inorganic solids	IS:3025:Part18:1996		$\ngtr$ 3000 mg/L
3.	Organic solids	IS:3025:Part18:1996		$\ngtr$ 200 mg/L
4.	pH@27°C	IS:3025:Part11:1996		$\ngtr$ 6
*5.	Sulphates as SO_4	IS:3025:Part24:1992		$\ngtr$ 400 mg/L
6.	Suspended matter	IS:3025:Part17:1996		$\ngtr$ 2000 mg/L

Water Neutralization

7.	To neutralize 100 ml of water (using phenolphthalein indicator) (NaOH)	$\ngtr$ 5 ml
	To neutralize 100 ml of water (using mixed indicator) (H_2SO_4)	$\ngtr$ 25 ml

Notes: 1. The tests for acidity and chlorides are the most important tests.
2. mg/litre = parts per million
*Ground water sulphates as SO_3 should be tested separately.

SUMMARY

Water is an important material in civil engineering construction. Water in which more than 400 mg *of chlorides are present per litre of water* should never be used for reinforced concrete works. But water with these results on chlorides can be used for mass concrete work. A specimen of the form used for water test for construction is shown in Table 9.1. Testing of groundwater for sulphates is also important in building construction.

REVIEW QUESTIONS

1. (a) Describe the routine tests specified for water used for reinforced concrete work
   (b) What is the most important test for groundwater for concrete work in foundation.

2. What are the restrictions for use of water in the following construction works
   (a) For mortar
   (b) For plaster
   (c) For reinforced concrete work
   (d) For curing plaster work and mass concrete works

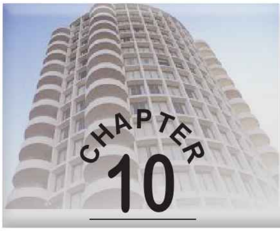
3. Which IS codes are used for (a) testing of water for sulphates for concreting and (b) testing of groundwater for sulphate for choosing type of cement in foundation?

4. What is the action of sulphates in groundwater on concrete construction? How do you prevent these ill effects according to IS (a) in water used for concreting (b) in ground water for protection of concrete works.

REFERENCES

[1] IS 456–2000: *Plain and Reinforced Concrete Code of Practice.*

[2] IS 3025 (in 56 Parts): *Methods of Sampling and Test (Physical and Chemical) for Water and Waste Water.* (See Table 9.1 for relevant parts.)



CHAPTER 10

Mortars and Plasters

10.1 GENERAL

Mortars are used in masonry for joining stones, bricks, blocks, etc. and plasters are used for rendering on the outside and inside of walls. The differences between mortar and plaster lie in the capacity of plasters to take better finish, which depend to a very large extent on the type of sand used in the mix (refer Section 7.6). For plasters we use finer sand. However, the term mortar is also used loosely to refer to both plasters and mortars. Mortars are designated by the mix used. Chapter 7 (Section 7.6) gives details of sands used for mortar and plaster. The following are the commonly used mortars for construction of ordinary buildings.

Cement and lime mortar. Cement mortar is a mixture of cement and sand while *lime mortar* is a mixture of slaked lime and sand.

Lime surki pozzolana mortar. It is a combination of lime, surki pozzolana and sand.

Combination mortar. It is a mixture of cement, lime and sand.

Thus, a 1 : 2 lime mortar means 1 part of lime to 2 parts of sand. In lime surki mortar, the sand is fully or at least 50 per cent replaced by surki. 1 : 2 cement mortar means 1 part of cement to 2 parts of sand. As lime gives plasticity and cement strength to the mortar, *combination mortars* are sometimes preferred in building works. 2 : 1 : 9 combination mortar will contain 2 parts of cement, 1 part of lime and 9 parts of sand by volume. Instead of using combination mortar, we can add propriety materials called admixtures like plasticizers to cement mortar to increase its workability. They are comparatively costly and the main advantages of these admixtures over lime is that it is difficult to get good lime easily nowadays and chemical admixtures can be stored easily at the site and will not deteriorate fast. The nature of sand to be used for mortars and plasters has been discussed in Section 7.6, Chapter 7. Mud mortar is made from plastic earth. It is mainly used only in low-cost construction work.

Thus, the four major types of mortars used in construction can be described as follows:

1. Lime mortar (fatlime, hydraulic lime and lime with surki (pozzolana) in different proportions))
2. Cement mortar (cement and sand in different proportions)
3. Combination mortar or gauged mortar (cement, lime and sand in different proportions)
4. Mud mortar (clay and sand to form a plastic mix)

The constituent materials are mixed with water to form a mortar or a plaster mix.

In this chapter, we will briefly consider the general requirements of mortars, the composition of each of these mortars and the tests prescribed for them.

10.2 REQUIREMENTS OF MORTARS AND PLASTERS

The following are the important general requirements of mortar:

1. Strength: It must have the required strength.
2. Workability: It must be workable (lime mortars are more workable).
3. Durability: It must be durable.
4. Compatibility with type of painting work (lime plaster does not match with some types of paint).
5. It should stiffen early. (Time rate of stiffening must be sufficient.)
6. It must have good bond with bricks.
7. It should prevent seepage of rain water. (Resistance to rain penetration should be high.)
8. It should have water retentivity. (Mortar should not easily part with water to bricks.)

The required strength of mortar depends on the strength of materials to be joined. There is no advantage in using over-strong mortar but *it should be sufficiently strong to match the strength of the materials like bricks or blocks to be joined.* It should also be easy to work with and should resist erosion, abrasion and other factors affecting durability. For low-strength bricks, it is the workability of mortar rather than its strength that determines the mix. *Of all the requirements, the four main requirements are strength, workability, durability and compatibility with the proposed painting work. (Lime plaster does not match well with many modern paints.)*

Even though addition of lime in mortars and plasters increases its plasticity and it is specified to be used, this rule is hardly followed nowadays in practice in the field. In most of the constructions, only simple cement mortars and plasters are commonly used.

10.3 PREPARATION OF LIME MORTARS AND PLASTERS

Ordinary lime mortars and plasters are made by grinding lime with sand. They have good working qualities, high water retention and freedom from shrinkage and cracking as compared to cement mortar. But they give only low strengths. Whereas 43 grade cement gives a laboratory mortar cube strength of 43 N/mm^2, lime mortar has a strength of only about 1.75 N/mm^2 in 28 days. The following are the usual three methods for preparing lime plaster (see Figure 10.1). The important point is that lime and sand should *be ground well to form* a fine mix.

The first method is to dry-mix the lime and sand in the specified proportion on a platform or more often in a trough. The necessary quantity of water is sprinkled in stages and the mixture is ground to a plastic mix by *pounding with heavy wooden hammers.*

The second method, adopted when a large quantity of mortar is needed, is to use a bullock-driven mortar mill. The mixture is ground at least for 180 revolutions to get a suitable mortar.

The third method, which is the modern method for preparing large quantities of lime mortar, is to use a machine-driven pug or mortar mill for making lime mortar. Mixing (or rather grinding) is done for at least three minutes for mortar for brickwork and longer for plaster

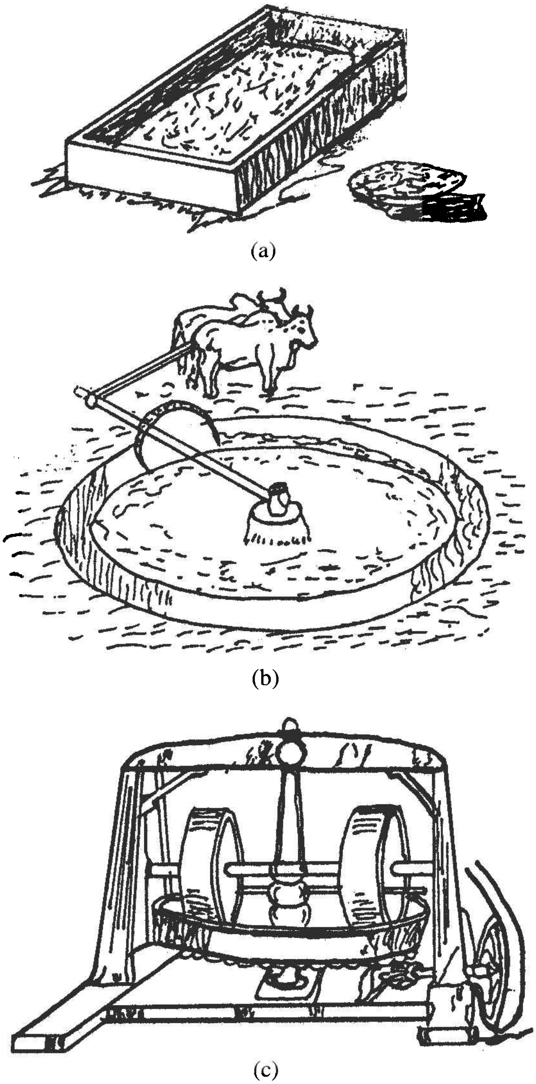


Figure 10.1 Grinding of lime mortar and plaster. (a) Mixing in a trough (b) Mixing in a bullock-driven mortar mill (c) Mixing in a mortar mill.

for plasterwork and pointing and terrace works. The grinding, thus, depends on the need for fineness of work. The mortar is raked up continuously during the process. Enough water is added to bring it to a stiff paste.

Ordinary lime mortar can be stored after mixing for a maximum period of 3 days (72 hours); but hydraulic lime should preferably be used within 2 to 4 hours after grinding. The ground pure lime mortar should always be kept moist by covering it with wet sack cloth and should not be allowed to be dried out. It is preferable to use lime putty instead of lime powder for making lime plaster for fine plasterwork. In this case, it is advisable to first grind the mortar and store it for some time in a damp condition for thorough slaking. It is again ground a second time to a fine paste. The plaster should be used immediately after the second grinding.

The usual mixes of *lime mortars and plasters* specified by volume are as follows:

(a) Mortar for brick or stonework—1 : 2 (1 lime and 2 sand)
(b) Plaster for first coat—1 : 1.5
(c) Plaster for second coat—(lime only as putty)
(d) Mortar for terrace work—1 : 1.5
(e) Mortar for flat tiles—1 : 1.5

Hydraulic lime mortars. In Chapter 4, we discussed that we can get hydraulic lime from naturally-occurring materials like kankar and also that fatlime can be made hydraulic by addition of pozzolanic materials like surki. These principles can be used in the preparation of various types of lime mortars as described earlier. These hydraulic mortars should be treated like cement mortar, which are described in the next section, and should be used within about 2 to 4 hours after mixing. Fatlime mortar does not set like cement mortar but stiffens as water is lost by absorption by masonry and evaporation. The strength is obtained by absorbing carbon dioxide from air which is helped by the addition of sand. Presence of water is not required for attaining the strength. This is a very slow process. For this reason, bricks need not be wetted while using lime mortar, whereas cement mortar should always be used with wet bricks so that the water in the mortar will not be absorbed by the bricks.

10.4 PREPARATION OF CEMENT MORTAR

Cement mortar needed for small works is hand mixed and that for large works is mixed by a mixing machine. A *concrete mixer* is suitable for the latter method.

Hand mixing. Cement mortar is hand mixed as follows: Sand is measured (preferably dry) by boxes and cement by weight of bags or by assuming that one bag has a volume of 0.035 m^3. The specified quantities of sand is spread first and then cement over the sand. They are then dry mixed by turning over and over, backward and forward several times by a shovel or spade till the mixture is of uniform colour. The quantity of mix that can be used within 30 minutes is then taken apart and mixed separately and formed into a heap. A small depression is made on top of the heap. Water is added to the centre of the heap and mixed well. The water should not be in excess to draw the cement out. Roughly the water required is 70 per cent of the weight of the cement for 1 : 3 mortar. The whole mass is mixed thoroughly for 10 to 15 minutes in hand mixing.

Machine mixing. In machine mixing, cement mortar can be mixed in a concrete mixer. The sand and then cement are discharged into the mixer. First, it is mixed dry and water is then added gradually. Wet mixing continued for more than one minute until the mixture is brought to a plastic mix. (The machine should be cleaned with water each time before suspending the work to prevent any setting of the mortar that sticks to the mixer.)

Cement mortar shall be used as soon as possible after mixing before it has begun to set within one to two hours. In case the mortar gets stiffened during this time because of evaporation of water from the mortar, it should be retempered by adding water and reworking it.

This is to be done as frequently as needed to restore the necessary consistency. Such retempering is permitted only up to two hours only from the time of addition of water to the cement. Thus, the usable time may be extended to two hours only if the mixture is kept agitated every 10 to 15 minutes. Mortar unused for more than two hours should not be used on the work.

The usual cement-mortar mixes specified by volume are the following:

(a) Masonry mortar for brick and stone masonry 1:5 to 1:8 (as per brick strength)
(b) Base coat of plaster, for covering masonry or for pointing 1:3 to 1:6
(c) A mix of 1:2 with-water proofing compound is used for plastering of inside of water retaining structures like water sumps and for damp-proof courses.
(d) Mortar for pointing and brick work below ground level 1:2 to 1:3
(e) Plaster for R.C.C. works 1:3 to 1:4
(f) For masonry in foundation, the mix slightly richer than that used for superstructure.

Notes:

1. Compressive strength of 1:6 mortar (to which enough water is added for workability) is between 2 to 5 N/mm^2 and that of 1:3 mortar is above 5 N/mm^2.
2. Generally, the inside of buildings is plastered to a smoother finish than the outside by using finer sands. For very high class buildings, the inside walls are further treated with wall putty or plaster of Paris before paints are applied. This gives a smooth finish to inside walls. Special wall putties are available for this purpose. Coarser finish outside is preferred for prevention of water penetration.
3. More specific mixes are given in Section 10.9.

10.5 PREPARATION OF COMBINATION MORTAR

While using lime and combination mortar, one should ensure that the lime is slaked well and if the available sand is coarse, then it should be initially ground well with lime to form an intimate mixture. For this purpose, first the lime and sand are ground well dry and then again ground with addition of the necessary water. The lime-mortar mix thus prepared is then transferred to a mechanical mixer to which the required cement and additional water are then added. Mixing is continued in the mixer for 3 to 5 minutes to obtain the required consistency. The mortar thus prepared should be used, as in the case of pure cement mortar within half an hour after adding water to cement. It may be extended up to 2 hours if it can be kept agitated every 10 to 15 minutes.

If fine sand is used instead of coarse sand, then the first grinding can be dispensed with. Combination mortar can also be prepared by making separately lime and cement mortars and then mixing them together. This is called *gauging*. The usual proportions of combination mortar used are the following. (They give a compressive strength of 3 to 5 N/mm^2.)

(a) Masonry mortar (Brick or stone)—1:1:6 to 1:1:8 (lime as plasticizer).
(b) Plasterwork—1:2:9 to 1:1:7 (1:2:9 means 1 part of cement, 2 of lime and 9 of sand)

Example of preparation. A 1:1:6 combination mortar is obtained by first mixing 1/2:3 lime mortar into a homogeneous mass with addition of necessary water to make it a workable mix. This is called the coarse stuff. This coarse stuff is mixed in a mixer with cement in the proportion 1:2 (1 part of cement and 2 parts of coarse stuff) resulting in 1:1:6 combination mortar. The necessary water to make a workable mix is also added in the mixer.

When factory-made dry hydrated lime powder is used, primary grinding of lime and sand can be omitted. Mixing may be also done in one operation in a mechanical mixture, when the ratio lime to cement in the mix is 1 or less than 1. Then the main function of the lime in the mix is to act as a plasticizer. In such cases, it is preferable to use non-hydraulic lime for the mix. The addition of a little cement to lime mortar to improve its strength is called gauging of mortar. The resulting mortar is called *gauged mortar.*

10.6 PREPARATION OF MUD MORTAR

Mud mortars can be made with or without waterproofing. Mud mortar is generally used for low-cost buildings and protection from rainwater should always be provided for such buildings by providing the necessary eves to the roof. Mud mortar is also used for temporary construction like a watchman's shed, which can be later dismantled.

(a) ***Mud mortar without waterproofing.*** The earth for the mud mortar should be of tenacious nature and specially selected. Sand is added to this earth in such quantity that when a sample of the mixture is mixed well with water and made into a ball which is allowed to get dry it should show no sign of cracking up. (The soil characteristics are to be the same for mud mortar with water proofing and is given below.) This mixture of mud and sand is well trodden and worked into the consistency of a thick paste by adding sufficient water. All the clods and stones are removed in the process. It is then allowed to get mature for a week with water standing on top of the mud in a shallow pool. It is then kneaded well by treading on it to the suitable consistency to be used for brickwork in mud. (Such mortars are used for construction of temporary works for arches etc.)

(b) ***Mud mortar with waterproofing.*** The soil to be used for mud mortar shall be such that 100 per cent will pass through 2.36 mm sieve and not less than 75 per cent pass through 850 microns sieve. The clay content shall not exceed 10 per cent. The Plasticity Index (P.I.) is to be between 6 and 7. If it has more P.I., then suitable quantity of sand passing through 2.36 mm sieve is added to bring the P.I. value within the specified range. Loamy soil has better adhesion to the sun-dried brick walls than granular soil.

Lime and bitumen are added to this soil as specified below to improve the waterproofing qualities of the mix. Hydrated lime 3 per cent by weight is added first and then 2 per cent by weight bitumen of penetration 80/100. (This bitumen is added as a solution prepared by adding 25 per cent by weight of kerosene to the 80/100 penetration bitumen brought to liquid form by slightly warming it.) Water is then added to the above soil mix and the whole mass thoroughly mixed by trodding bring it to a workable consistency.

10.7 OTHER TYPES OF MORTARS

Some of the special mortars used in special conditions are given below:

1. ***Fire-resistant mortar.*** This mortar is to be used with fire bricks in ovens: chimneys, etc. It usually consists of one part of aluminous cement to 2 parts of powder of fire bricks in place of sand. (The usual proportion is 1:2.)

2. ***X-ray shielding mortar.*** For plastering walls and ceiling of X-ray cabinets, we use a heavy mortar made from heavy rock (like barite, magnetite, hematite, etc.) sand. Suitable admixtures are also added to make it.
3. ***Latex-based polymer SBR (Styrene Butane Rubber) mortar.*** Latex is a milky white liquid obtained from styrene and butadiene by high pressure emulsion polymerization. It contains synthetic rubber dispersed in an aqueous solution. It is said that even if we add natural latex (instead of synthetic rubber) to cement mortar, it improves the impermeability and also the adhesive qualities of the mortar by filling the voids of the mortar. This type of mortar is very useful for repairing R.C. beams in which the covers have fallen off due to corrosion. Usually 10 litres of SBR latex is added to one bag of cement. The mortar made by this cement in the ratio 1 : 3 is extensively used as a concrete repair material. First, a cement slurry coat with 1 : 1 (cement : SBR) is applied as a bond coat for improving the adhesion of the new mortar to the old concrete surface, and then the 1 : 3 mortar with SBR cementmix is applied to rebuild the surface (see also Section 12.7 and Section 23.6).

10.8 SELECTION OF CEMENT FOR CEMENT MORTARS

There is no advantage in using high-strength cements like grade 53 for plasterwork. In fact, high strength and high cement content plaster produces more plaster cracking than low strength (grade 33) and low cement content plasters. The aim of the composition of the plaster is to get a very workable mix which will have low shrinkage, so that it does not crack on shrinkage. It has been found that addition of lime gives plasticity to the mortar or plaster. Hence, combination mortars are more workable than pure cement for plasters. Similarly, the cheaper grade 33 Portland pozzolana cement is better for plastering than the costlier 53 grade cement.

10.9 REQUIRED STRENGTH OF MORTARS IN MASONRY

Strength of mortars to be used for joining bricks, stones, blocks, etc. should depend on the strength of the materials to be joined. There is no advantage in using over-strong mortar, but it should be sufficiently strong to resist erosion, abrasion and other factors affecting durability. When mortars of strength higher than the brick or block units are used, cracks due to settlement or shrinkage tend to be large and concentrated in a few places instead of being distributed at all the joints as when using lower strength mortars. We have dealt with the range of cement-mortar mixes in Section 10.4. The following list gives the composition of common cement-sand mortars and cement-sand plasters used in practice in *Tamil Nadu where the strength of brick is low.*

A. Cement mortars

1. Damp-proof course 1 : 2
2. General brickwork (using stock bricks) 1 : 6
3. Stone masonry 1 : 6
4. For arch work 1 : 3
5. Pointing work 1 : 1 to 1 : 3
6. Brickwork below ground level 1 : 3 to 1 : 4 recommended

B. Cement plasters

1. Brickwork plaster (external) 1:5 to 1:6 (usually 1:5)
2. Brickwork plaster (internal) 1:5 to 1:6 (usually 1:5)
3. R.C. plasterwork (like ceiling) 1:3 to 1:4 (usually 1:4) (Leaner plaster will not have enough cohesion to stick to concrete work.)

Tables 10.1, 10.2 and 10.3 give the approximate strength of cement-sand and cement-lime-sand mixes for recommending mortars to be used based on brick strength. (It is to be noted that mortar recommended should have the same strength as the bricks used to get the full use of its strength.)

Table 10.1 Approximate Strength of Cement-Sand Mortars

No.	Cement-sand mix	Strength N/mm^2	Type (Strength)
1	1:3	10	High
2	1:4	7.5	High
3	1:5	5.0	Medium
4	1:6	3.0	Medium
5	1:8	0.7	Low

Table 10.2 Approximate Strength of Combination Mortar and Lime Mortar (IS 1625-1971)

No.	Cement : lime : sand fat	Strength N/mm^2	Type (Strength)
1	1:½:4½	6 to 8	High
2	1:1:6	3 to 5	Medium
3	1:2:9	2 to 3	Medium
4	1:3:12	0.7 to 1.5	Low
5	0:1:2	0.7 to 1.5	Low

Table 10.3 Recommended Mortars for Various Bricks

No.	Brick strength (N/mm^2)	Mortar mix	Strength of mortar (N/mm^2)
1	Below 5	1:6 or 1:2:9	3
2	5 to 15	1:5 or 1:1:6	5
3	15 to 25	1:4 or 1:½:4½	7.5
4	> 25	1:3 or 1 : ¼ : 3	10

10.10 COMPRESSIVE STRENGTH OF BRICK MASONRY

If a brick wall made from bricks and mortar is tested under compression, then we will note that the wall fails not like a brick subject to compression. In fact, the brick bedded on the mortar behaves as a beam on an elastic foundation. The failure of the wall will be due to the failure in tension of bricks acting as small beams resting on the mortar bed. Thus, the wall generally cracks up at a stress equal to the tensile strength of bricks which is only about 1/10th the compression strength of the bricks. Accordingly, we should understand clearly that the strength of mortar required is only to bond the bricks together. In general, it should not be much greater than the strength of the bricks used in construction. In fact, even if the strength of mortar is much larger than the strength of bricks, then the allowable compressive strength of brickwork will not be much more than 1/10th the strength of bricks. Hence, mortar of strength that is comparable to the strength of the bricks being used is only required in masonry construction.

10.11 TESTS FOR MORTARS

The usual tests prescribed for mortars are the following:

1. Compression (crushing) strength
2. Tensile strength
3. Test for adhesion to brick
4. Test for brickwork in compression

These tests are briefly described further.

10.11.1 Compression Strength

The mortar is compacted into cube moulds of 70.6 mm and tested as described in tests for cements in Section 5.10.5. Cement mortar is cured in water and lime mortar in air. These cubes are tested after the specified days, usually 28 days.

10.11.2 Tensile Strength

The briquettes for testing mortar are of the shape as shown in Figure 10.2. They are 38 mm × 38 mm or 1½ inch × 1½ inch in section as compared to briquettes used for cement tests which are 25.4 mm × 25.4 mm or 1 inch × 1 inch in section. The cement mortar should be cured in water and lime mortar in air. The briquettes are tested in the special briquette-testing machine.

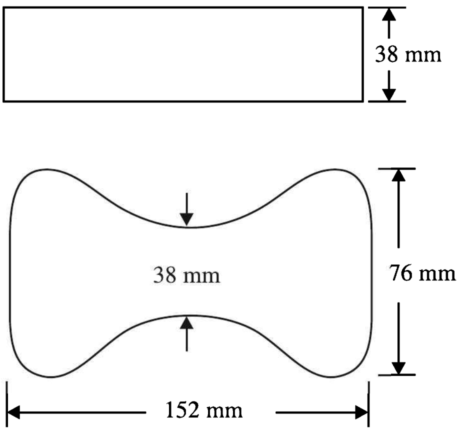


Figure 10.2 Briquette test for tensile strength of lime mortar (Area = 14.44 mm2).

10.11.3 Test for Adhesion

A set up as shown in Figure 10.3 is used. It is tested after curing it for 28 days. The stress required to separate the bricks is the adhesion strength.

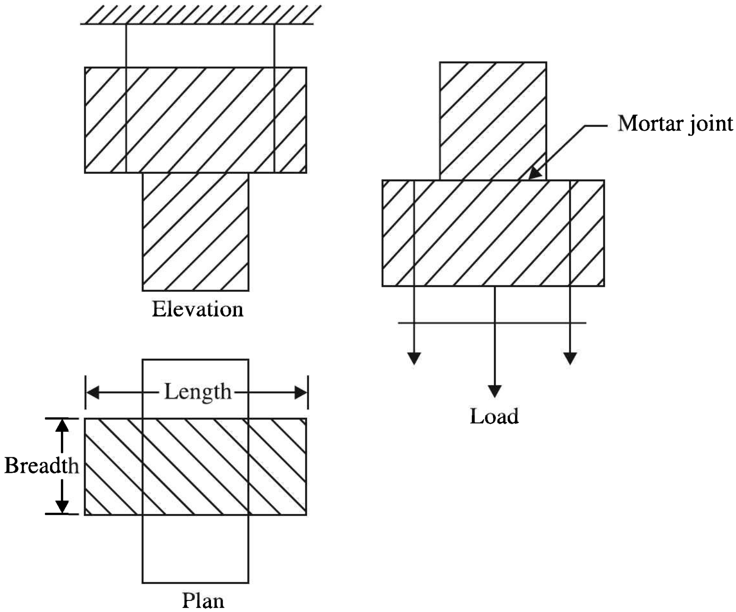


Figure 10.3 Test for adhesiveness of mortar.

10.11.4 Test of Brickwork in Compression

In some cases, in order to find the available strength of masonry, a square column of brickwork having bricks of breadth 1½ inch and of height not less than twice the breadth is made with the mortar and tested in compression. The load at which the first cracking appears and also the load at the final failure loads are noted. The strength is usually taken as the load at first crack.

10.12 ESTIMATION OF CEMENT FOR PLASTER

Table 10.4 Materials for 1.2 m^3 Plaster (@ 12 mm for 100 m^2)

Mix	Cements (in bags)	Sand (in m^3)
1:3	15	1.5
1:4	12	1.6
1:6	9	1.8

Note: In brick work 30% volume is assumed as mortar.

SUMMARY

For construction of buildings, nowadays, we mostly use cement mortars and cement plasters. A large amount of cement is consumed for these works. The total consumption of cement is about 3 bags per square metre of plinth area in residential buildings and about 4 bags per square metre of plinth area in office buildings of this a major part is used for making mortar and plasters. Lime, if available at site in good quality and reasonable price, can be used to improve the plasticity of mortars and plasters. Special waterproofing and plasticising chemicals are also available to be used as additives.

REVIEW QUESTIONS

1. (a) Describe the difference in the development of strength of lime mortar (using fatlime) and cement mortar used in brickwork. Why is it not necessary to wet the bricks when building brickwork with ordinary lime mortar and why such wetting is necessary with cement and hydraulic lime?

(b) Why is it preferable to grind lime mortar instead of mixing as is done for preparing cement mortar?

(c) What machine would you use for preparing lime mortar on a large scale?

2. Give the four major types of mortar used in building construction. Briefly describe hand mixing and machine mixing of cement mortar.

3. (a) Describe the procedures for preparing lime mortar.

(b) What mixes of lime mortar would you recommend for the various items of building construction?

4. (a) Describe the procedure for preparing combination mortar? What is the advantage of using combination mortar in brickwork? Can this advantage be achieved by any other means?

(b) What mixes of cement mortars and plasters would you recommend for the following building works:

(i) Brickwork in foundation

(ii) Brick work in superstructure

(iii) Base coat of external plaster for masonry

(iv) Base coat for internal plaster for masonry

(v) Plastering of underside of roof slab

(vi) Plastering of a underground water tank in brickwork

5. Distinguish between mortar and plaster? What are the differences in the preparation of cement mortar and cement plaster?

6. Describe the important tests you will make to determine the quality of cement mortar for brickwork? Find cement for 10 m^3 of brick work in 1:6 mortar.

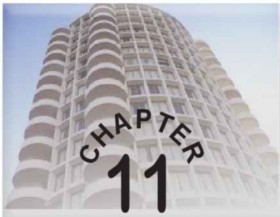
REFERENCES

[1] IS 1635–1992: *Code of Practice for Field Slaking of Building Lime and Preparation of Putty*

[2] IS 2250–1981: *Code of Practice for Preparation and Use of Masonry Mortars.*

[3] IS 2645–2003: *Integral Cement Waterproofing Compounds for Cement Mortar and Concrete—Specification.*

[4] IS 13077–1991: *Preparation and Use of Mud Mortar in Masonry-Guide.*



CHAPTER 11

Cement Concrete

11.1 INTRODUCTION

Cement concrete is a major building material used in modern building constructions. It is used in all parts of a building like foundations, superstructure and roofs. In many places in India, it is prepared at site by hand mixing or machine mixing. In the major towns and cities in India, it is now available as a factory-made product known as "Ready Mixed Concrete" (RMC). In this chapter, we will deal with concrete as a construction material. The construction aspects of concrete like mixing placing etc. are dealt in books on building construction. As it is a vast subject, still developing, we will examine only the fundamental aspects of making concrete for use in building construction.

11.2 HISTORICAL DEVELOPMENT

Modern manufacturing of *Portland cement* was patented by Joseph Aspdin in 1824. Even before that, cement obtained by calcining clay and limestone called *hydraulic cement* was available and used with stones as mass concrete for buildings. The first use of concrete with steel, as reinforced concrete, was made in 1850 by J. L. Lambot of France to build a rowing boat. In the last 150 years, reinforced concrete and prestressed concrete have been developed as seperate specialized subjects.

11.3 INGREDIENTS OF CONCRETE

Till recently, the ingredients of concrete were only the following:

1. Cement
2. Fine aggregate (sand)
3. Coarse aggregate (broken stones or gravel)
4. Water

However, recently, a large number of additives known as concrete additives are also added as ingredients of concrete to make concrete of qualities required for various constructions. Some of the additives used are the following:

1. Plasticizers
2. Superplasticizers

3. Accelerators
4. Retarders
5. Pozzolanic material
6. Air-entraining agents
7. Fibres
8. Polymers
9. Silica fume.

11.4 WATER-CEMENT RATIO

The most important property of concrete is its high compressive strength. It is easy to produce a field concrete with a compressive strength up to 20 N/mm^2 with modern cements. Specially designed concrete can have strength up to 80 N/mm^2. As the compressive strength of the coarse aggregate is always very high, the compressive strength of concrete is greatly influenced by the strength of the cement paste which, in turn, depends on the "water-cement ratio." We define water-cement ratio as the ratio of the weight of mixing water to the weight of cement used in the concrete. The strength of concrete increases with decreasing water-cement ratio. The laws governing this property are more fully dealt with in Chapter 13.

11.5 SPECIFICATIONS FOR CONCRETE

Concrete when used on construction works is specified in one of the following ways:

(i) For non-structural work as "*prescribed mix*" in terms of the volumes of the constituents of the mix and the maximum size of aggregate used. Thus, 1 : 2 : 4 (20 mm) concrete means one part of cement, two parts of fine aggregate and four parts of coarse aggregate of maximum size 20 mm.

(ii) For structural work as "*designed mix*" in terms of the grade and the maximum size of aggregate used. The grade denotes the 28-day cube strength in N/mm^2. The strength of concrete is determined by casting it in 15 cm (6 inch) cube moulds, curing it in prescribed conditions and then testing it after 28 days. Thus, grade M20 (20 mm) concrete means that its 28-day cube strength is 20 N/mm and maximum size of aggregate used in 20 mm. The minimum grade of concrete specified by IS 456 (2000) for structural work in buildings is M20. For structural work, from durability considerations, it is also common to specify the maximum water-cement ratio also. However, as the maximum water-cement ratio allowed in IS 456-2000 is 0.55; if the w/c ratio is not specified, then it is understood that it should not exceed 0.55.

It has been found of late that the durability of concrete structures is very much affected by water-cement ratio and also the cement content. Hence IS 456–2000 *also specifies* that the *minimum cement content* (inclusive of admixtures like flyash) in all structural concrete should not be less than 300 kg/cm^3. IS 456–2000 also specifies that the *maximum cement content* (exclusive of admixtures) allowed should not be more than 450 kg/m^3 unless special steps are taken for the increased cement content. Examples of specification of concrete can be as follows:

1. For non-structural work, it is specified by volume 1:2:4 (50 mm). This means 1 part of cement, 2 parts of fine aggregate (sand) and 4 parts of coarse aggregate (broken stones) of maximum size 50 mm.
2. For structural work, it is specified by grade. Grade M20 (20 mm) concrete means concrete of 28-day strength of 20 N/mm^2 with maximum w/c ratio 0.55 (if a lesser w/c is needed, that also should be specified) and minimum cement content of 300 kg/m^3 of concrete, with 20 mm coarse aggregate.

In practice, however, we do not design all the mixes that we use for construction. Experience has shown that the following relation exist between the specification by volume and the grade of concrete for 20 mm aggregate concrete of maximum size and given w/c ratio. With higher w/c ratios than shown, we will get lesser strengths (Table 11.1).

Table 11.1 Strength of Concrete Mixes with Modern Cements

No.	Mix	Grade	Cement content kg/m^3	w/c ratio*
1	1:1:2	30	552	0.35
2	1:1½:3	25	405	0.45
3	1:2:4	20	320	0.55
4	1:3:6	10	227	0.75
5	1:4:8	–	173	0.80

Notes: 1. *As the volume of water needed for workability per cubic metre of concrete is more or less the same; with higher cement content, we can get the same workability with less w/c ratio.
2. No. 4 and 5 are not to be used for structural work.

11.6 PROPERTIES OF CONCRETE

The main desirable properties of concrete are the following:

1. It is very strong in compressions. In reinforced concrete, compression is taken by concrete and tension by steel.
2. It is durable. Concrete is very durable under normal conditions of exposure. However, concrete with ordinary Portland cement (OPC) disintegrates in sulphate waters like sewage and hence, special cements should be used in such situations.
3. It can be moulded into any form. Concrete can be poured into any mould when it is fresh and it takes the shape of the mould after it sets and hardens. Beams, slabs, shells of any size and shape can be made because of this property.
4. Its expansion matches with that of steel. Even though the coefficient expansion of concrete depends on the aggregates used, its value with the common types of aggregates is around 10×10^{-6} to 14×10^{-6} per degree centigrade and that of steel 13×10^{-6} per degree centigrade. Hence, there is compatibility between the two in the usual range of temperatures. *This is one of the reasons that concrete and steel match well and reinforced concrete is durable with temperature changes.* Thus, in situations where concrete is exposed to large variations of temperature difference in the coefficients of

expansion of the aggregate and steel should not be more than 5.4×10^{-6} per degree Centigrade.

5. It prevents steel from corrosion. Good impermeable concrete protects steel from corrosion. Steel corrodes when exposed to air, by forming rust, which has over 2.5 times the volume of steel. This expansion causes destruction of concrete. However, if steel is enclosed in good concrete, then it prevents the steel from rusting. This is primarily due to the alkalinity condition provided by the concrete cover. Hence, concrete cover is very important in R.C. works.
6. It is economical in cost. Concrete compared to other manufacturing materials like steel is low in cost.
7. It can be made of the materials available locally. One of the important rule in civil engineering construction is that we must always try to use thematerials available locally. For making concrete, cement, which can easily be transported to any site, is the only material that is not available locally. The cement content is also only about 12% of the total weight of concrete.
8. It can be manufactured to special requirements. Concretes like high strength concrete, self compacting concrete, air entrained concrete, pumpable concrete can easily be designed and made by use of concrete additives.
9. As it is heavy in weight, it is the ideal material for gravity structures like dams and retaining walls.

The main undesirable properties of concrete are as follows:

1. It undergoes shrinkage. Concrete has initial shrinkage when it sets and it also shrinks while hardening. (However, it is because of this property that it grips firmly to the enclosed steel and gets good bond strength.)
2. It requires careful attention in manufacturing, placing and curing. Concrete is a special material. It should be mixed and compacted properly as well as cured. Unless proper attention is given in all the processes, it can become defective.
3. Concrete members like beams and column will be bigger and heavier than steel members to carry the same load. Hence concrete structures tend to be heavier than steel structures.

11.6.1 Factors Influencing Strength of Concrete

The three important factors that influence the strength of concretes in addition to w/c ratio are:

1. Selection of materials and their preparation
2. Method of placing
3. Method of curing

11.7 MIXING, PLACING AND CURING OF CONCRETE

1. ***Mixing of concrete.*** As already pointed out in rural places in India and for small works, concrete is mixed by hand. If the work is of large size, then a proper concrete mixer is used. In cities, it may be available as factory-made ready mixed concrete as

Ready Mixed Concrete (RMC). Both hand mixing and machine mixing are carried out in ordinary building construction in India.

It the constituent materials are not in proper proportions or they are not properly, mixedthen all the ingredients may not be distributed uniformly to make the mix a homogeneous mass. This separation of materials is called *segregation*. It can also happen if mixed concrete is poured from a large height.

2. ***Placing of concrete.*** Concrete is placed in moulds which are called formwork made of wood, steel, plastics, etc. As all the air voids present in the mix should be driven out, it has to be compacted by proper rodding or using concrete vibrators. In members like concrete piles, where it is not possible to use external methods to compact the concrete, it is necessary to design the concrete to compact by itself. Such concrete is called *self-compacting concrete*. One of the easiest way to do it is to increase the water content in the mix and thus increase the slump. There are also *additives called plasticizers and superplasticizers* which can be used for this purpose. In many multistoreyed buildings built in the cities, concrete is placed in the top floors by concrete pumps. This requires the concrete to be designed as a *pumpable concrete*.
3. ***Setting of concrete.*** After placing the concrete in the formwork, the concrete begins to harden. The initial stage of this hardening is called *setting* as in cements. However, the setting time as defined by concrete technologists need not be the same as defined by cement technologists. There is no separate test specified for setting time of concrete.
4. ***Curing of concrete.*** After the concrete has set, it should continuously cured (never allowed to dry out) for a specified period. The chemical reaction between the constituents of cement takes a long time to be completed. *It also takes place only in about 95% humidity*. Hence, it is necessary to cure the concrete by keeping the concrete wet for a specified period. If concrete is not properly cured, then shrinkage cracks appear on top of the cast concrete and also concrete will not attain its full strength. We should note that curing of concrete, especially in the early periods of the concrete, is very important in construction. Concrete should never be allowed to dry out during the curing period. According to IS 456 clause 13.5.1 the period of curing depends on the cement used. For OPC it is taken as at least 7 days from the date of placing concrete if the concrete is always kept wet by ponding or covered with sacking canvass or *hessian* (jute cloth). It should be cured for 10 days at least if the concrete is exposed to dry and hot weather conditions. The period of curing for cements containing mineral admixtures (the cements now available in the market in bags) it should be a minimum of 10 days and 15 days respectively for the above two conditions. Thus for PPC the period of curing required is much longer.Curing can be done by the following methods:
   - (a) Ponding with water
   - (b) Covering concrete with hay, sand, jute bags, etc. and watering these coverings
   - (c) Intermittent spraying and covering concrete with polythene bags
   - (d) Applying curing compounds immediately after wetting the concrete after final set so that moisture in the concrete does not dry out
   - (e) Completely immersing in water tanks as with precast elements
   - (f) Accelerated curing by heating with wet heat as with steam curing or with hot water.

11.7.1 Bleeding of Concrete

Water being the lightest ingredient in the wet concrete mix, it tends to move upwards and collectat the top. This is called bleeding. When water collects at the bottom of the aggregates or reinforcement, it is specically called *internal bleeding*. The excess water content in the concrete at the top makes it weak and porous. Bleeding can be reduced by proper propertioning and complete mixing of ingredients. Use of finely divided materials like fine cement, excess cement or finely divided pozzolanic materials reduces bleeding by creating more resistance for the water to flow upwards.

11.8 TYPES OF CONCRETE

These are many types of concrete that can be made as per the requirement. In the ordinary concrete, the following distinction is usually made.

1. ***No fines concrete.*** It is designed with cement, coarse aggregate and water with no fine aggregates. This is generally used in mass concrete work in foundation where we want to delete capillary rise of water.
2. ***High-slump or self-compacting concrete.*** In situations like concreting of piles, we cannot compact the concrete by external means. Similarly, in places where there is a congestion of steel, we need this type of concrete. These are produced by increasing the workability of concrete by the aid of plasticizers and superplasticizers.
3. ***High-strength concrete.*** Concrete which is designed to have strength 40 N/mm^2(Grade 40) and above is called high-strength concrete. As will be seen in the chapter of concrete mix design, we can get concrete of strength up to 35 N/mm^2 with ease with most aggregates. However, beyond that strength, many other factors like type of aggregate, gradation of aggregates, cement–aggregate ratio, etc. become important. Hence, design of high-strength concrete mixes will be different from that of ordinary grade concrete. Modern high-strength concrete uses silica fumes and superplasticizers as additives. (This is further explained in Chapter 13.)
4. ***High-performance concrete.*** This is a term used for concrete which should have not only strength above 60 N/mm^2 (M60) but also other special attributes like high workability, high resistance to corrosion. This term is a modern term indicating that the concrete should have *all the qualities necessary for the work*. The concrete should perform its intended use extremely well and it should be designed specially for it.
5. **5.** ***Other types of concrete.*** There are many other types of concrete. Some of them are described in Chapter 12, Section 12.1.

11.9 TESTS ON CONCRETE

There are many tests that are prescribed for concrete. Some of them are meant to test the quality of fresh concrete while others are meant to test the strength of hardened concrete. As these topics are dealt with in detail in Concrete Technology which is taught as a special subject in later years, all of them are not given in detail in this book. Only the most important field and laboratory tests to be carried out, are discussed here.

11.9.1 Tests on Fresh Concrete

The following are the important tests to be done on fresh concrete at the site as soon as it is discharged from the mixer or when it is delivered as RMC. They test the placing quality of the concrete.

1. Slump test (for plastic workability)
2. Campaction factor test (for stiff concrete)
3. Vee-Bee test (for quality of concrete with respect to cohesiveness, consistency and tendency for segregation)
4. Bleeding test
5. Setting time

11.9.2 Tests on Hardened Concrete

The following tests are needed to check the final product—the hardened concrete.

1. Compression test for compressive strength
2. Tension test for tensile strength
3. Flexure test for modulus of rupture
4. Additional tests like Schmidt rebound hammer test, ultrasonic test as prescribed

Of these tests, we will examine the following tests in the following sections:

1. Slump test
2. Compaction factor test
3. Compression test on concrete
4. Testing for tensile strength of concrete
5. Testing for modulus of rupture

[A visit to the laboratory is needed for a better understanding of these tests.]

11.10 SLUMP TEST

The standard apparatus for this test is the slump cone as shown in Figure 11.1. It is used to measure the workability of concrete. Workability is used to define the ease or difficulty with which the concrete can be handled, transported and placed. IS 456 gives workability in terms of slump of the concrete.

Slump test is carried out in the field or laboratory as follows:

The slump cone is placed on a G.I. sheet with the person conducting the test standing with his foot placed on each of the foot pieces. A quantity of concrete which will be slightly more than necessary to fill the cone is taken in a tray and thoroughly mixed together as quickly as possible after the concrete is discharged from the mixer. The cone is first filled with concrete to one-fourth of the volume of the cone and rodded 20 to 30 times with a rod 16 mm in diameter and 60 cm in length. The cone is thus filled in four layers with the above roddings. The top level of concrete is finally stuck off so that the cone is full of concrete. The cone is then gradually lifted and concrete is allowed to slump. The slump is measured as shown in Figure 11.1.

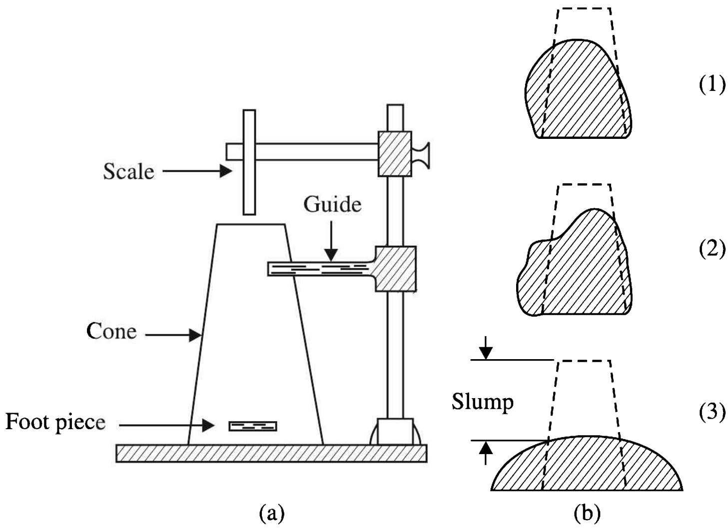


Figure 11.1 Slump test (a) Slump cone (b) Different types of slumps (1) true slump (2) shear slump (3) collapse slump.

11.10.1 Compaction Factor Test

A stiff concrete will give no slump. To test harsh (no slump concretes), the compaction factor test in used. The apparatus consists of a cone at a higher level, another cone at a lower level and a 150 mm diameter cylinder. The test consists of placing the freshly-cast concrete in a cone at a higher level, it being allowed to fall freely to a lower cone at a lower level and then to a cylinder placed below it at a fixed distance. The ratio of the weights of concrete filling the concrete by this fall to the weight of concrete that can be filled in the cone by vibration is the compaction factor. The relation between slump and compaction factor is shown in Table 11.2.

(*Note:* The Vee-Bee test is used for concrete of lesser workability. The apparatus consists of a cone and vibrating table as can be seen in the laboratory.)

Table 11.2 Classification of Concrete Mixes—Relation between Slump and Compaction Factor

Slump in mm	Workability and use	Compaction factor
Very stiff	No Slump	0.70
0 to 25	Stiff—to be used with vibration	0.75
25 to 50	Stiff plastic—mass concrete	0.85
75 to 100	Plastic—normal R.C.C. work	0.90
150 to 175	Flowing—for cast in situ pilework	0.95

11.11 COMPRESSION TESTS ON CONCRETE

The compressive strength test is used for specifying grade of concrete in design and for quality control of field concrete. It is described in IS 516–1959. The test is carried out as follows. While India and Europe use testing of 150 mm cubes U.S.A. has prescribed testing of 150 mm diameter and 300 mm long cylinders. For field control, the cubes are cast and cured in the field. Testing is conducted in the field or an approved laboratory.

1. ***Sampling.*** The scale of sampling varies with quantity of work. It varies from one set of three samples for 1 to 5 m^3 of concrete to four samples for 50 m^3 of concrete.
2. ***Preparation of specimen.*** Approximately equal proportions of concrete at three different times during the discharge from the mixer is taken and mixed thoroughly to form a set of three specimen for a single test. The specimens are made in 15 cm cube moulds. If they are manually made, then the concrete is placed in three layers and each layer is rodded 35 times with 16 mm rod 60 cm in length. Alternately, if the concrete is harsh, then it is placed in the mould by a vibrator in the same way as placed in the field. (The American practice is to cast 15 cm × 30 cm cylinders for compression test.)
3. ***Curing and storage.*** The cubes are first cured under wet straw or gunny for the first 24 hours. Then they are demoulded and stored in a room at a temperature of 24 to 30°C (27°C average) for 7 or 28 days till it is to be tested under saturated (wiped dry) conditions. Though both 7 days and 28 days strengths are taken, the latter strength is taken as the standard strength of concrete.
4. ***Method of testing.*** The dimension of cubes are first measured and the cubes are also weighed and tested in a machine. (These data will give us the density and compaction of the concrete.) The loads being applied to the sides of the specimen as cast. The rate of loading should be approximately 14 N/mm^2 per minute till failure of cube. The type of failure is also noted. The load in N/mm^2 gives the strength. The average strength of the set of three samples (with the individual strength not varying ±15%) is taken as the cube strength. (The weight of the samples can be used as an indication of the cause of any variation of strength. If 15 cm diameter 30 cm high cylinder specimens are made as specified in American Code, then they should be capped before testing. The cylinder strength is about 0.8 times the cube strength.)

11.12 TESTING FOR TENSILE STRENGTH

Tension test is conducted by the split test or Brazilian test. In this test, a cylinder specimen of 15 cm diameter and 30 cm height is loaded along its length in compression as shown in Figure 11.2. Tension is created along the diameter and the cylinder splits into two halves.

$$\text{Tensile strength} = \frac{\text{Compression load along axis}}{\text{Area in tension}} = \frac{2P}{\pi DL}$$

where

P = load

D = diameter of the cylinder and

L = length of the cylinder

Instead of a cylinder, a cube may also be used for the test.

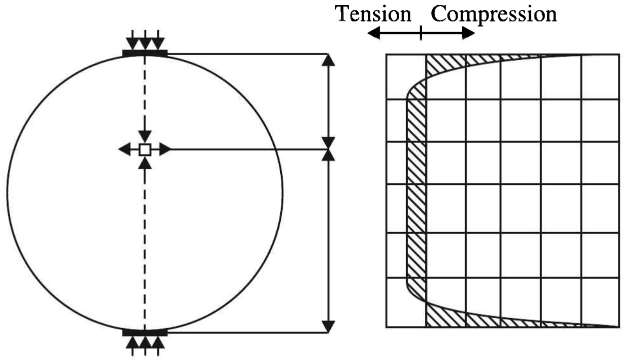


Figure 11.2 Tension test on concrete cylinder (a) Load along the length of cylinder (b) Distribution of tension across diameter. (Note: For arrangements for tension test on cubes see Advanced Rainforced Concrete Design by P.C. Varghese published by Prentice Hall of India.)

11.13 TESTING FOR MODULUS OF RUPTURE

A measure of the tensite strength of the extreme fibre in bending of a unreinforced concrete beam is called the modulus of rupture. It is determined by casting a small beam of the concrete and testing it in bending as shown in Figure 11.3. The standard size of beam used is 15 cm × 15 cm × 70 cm. For concrete made of aggregates less than 20 mm, it can be 10 cm × 10 cm × 50 cm. Theoretically its value is twice the value in tension.

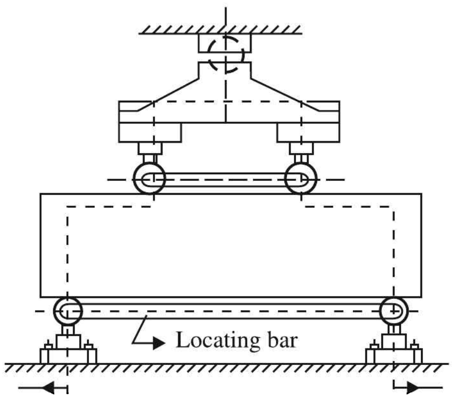


Figure 11.3 Test for modulus of rupture.

SUMMARY

Concrete is an important material in construction industry. All civil engineers should have a good knowledge of the fundamentals of the subject. Because of its importance for civil engineers, a full course in concrete technology is usually included in the later years in the civil engineering curriculum. The routine tests generally carried out for quality control of concrete for building construction are only the slump and the compression strength tests.

REVIEW QUESTIONS

1. Enumerate the important ingredients used in modern concrete?
2. (a) Explain what is meant by grade of concrete. What is the lowest grade of concrete allowed for structural work in buildings?
   (b) What grade of concrete will a 1 : 2 : 4 concrete mix give? What does C53 indicate in concrete technology?
3. (a) What new materials other than aggregates, cement and water are used to make modern concrete.
   (b) Explain what is meant by bleeding of concrete. How can we reduce it?
4. How do you specify concrete for (a) non-structural work and (b) structural work?
5. Explain the terms (a) nofines concrete b) self-compacting concrete. Give one situation for each of these, where it is used in practice.
6. What is the principal law that governs the strength of concrete? Why is it necessary to cure concrete? What precautions would you take in curing PPC concrete?
7. Enumerate the important test specified for concrete in building construction for testing. (a) Fresh concrete, and (b) hardened concrete. Indicate the use of each test.
8. Describe (a) slump test and (b) compression, strength test on concrete specify at what stages of making concrete do we make these tests?
9. What is meant by segregation of concrete? If the concrete is too harsh for a slump test, then what alternative fest would you prescribe?
10. Briefly describe the two tests you will prescribe to estimate the tension strength of concrete.
11. What is the size of specimen used for compression test on concrete :(a) in India (b) in U.S.A.? Which will give higher strength and what is the approximate ratio of these strengths?

REFERENCES

[1] SP 23–1982 :*Handbook on Concrete Mixes.*

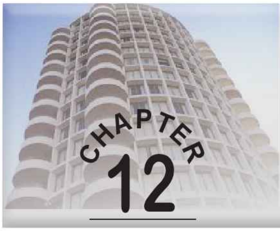
[2] IS 1199–1959 :*Methods of Sampling and Analysis of Concrete.*

[3] IS 7861 :*Code of Practice for Extreme Weather Concreting—Part 1 :1975 Recommended Practice for Hot Weather Concreting; Part 2 :1981 Recommended Practice for Cold Weather Concreting.*

[4] IS 516–1959 :*Methods of Test for Strength of Concrete.*

CHAPTER 12

Special Structural Concretes



12.1 INTRODUCTION

In addition to the normal cement concrete described in Chapter 11, a large number of special types of cement concretes are made for special purposes. The principal special concretes used for structural work are the following.

1. Fibre reinforced concrete
2. Light-weight concrete
3. Flyash concrete
4. High-strength/high-performance concrete
5. Silica fume concrete (very high-strength concrete)
6. Polymer concrete
7. Ferrocement
8. Ready-mixed concrete
9. Pre-packed concrete

In the following sections, we will deal with each of the above-mentioned concretes very briefly.

12.2 FIBRE REINFORCED CONCRETE (FRC)

It is the kind of concrete to which various fibres of very small diameter and short lengths (for example, steel fibres 10 to 20 microns in diameter and 10 to 50 mm length) are added to make a concrete. This material has increased tensile strength, resilience, flexibility and other qualities. The fibres may be steel, glass, polymer, carbon or even natural fibres like coconut fibre. As glass reacts with cement, special care should be taken while using them. Fibre reinforced concrete has been used as overlays for pavements in airports, bridges and over industrial floors. It can also be used in structures where increased resistance to cracking is needed.

12.3 LIGHT-WEIGHT CONCRETE

Light-weight concrete is generally made from light-weight aggregates like expanded shale, foamed slag, etc. These aggregates can also be prepared artificially from special clays which when heated to 1000–1200°C bloats or expands and become light in weight. Brickbat concrete is also a sort of light-weight concrete. It is used as filling-concrete in bathrooms, terraces, etc. It also acts as a thermal insulation compared to normal concrete.

Aerated cement mortar (without large size aggregates) is referred to as aerated concrete. We have already dealt with light-weight aerated concrete in Section 3.6.

12.4 FLYASH CONCRETE

Concrete using flyash is called flyash concrete. In Chapter 6, flyash is described as a pozzolana. Flyash obtained from lignite is superior to that obtained from coals. Flyash can be used to replace cement or the fine aggregate or to replace partially both. Up to 20 per cent replacement of cement and 30 per cent replacement of fine aggregates have been reported. The addition of flyash is said to improve the impermeability, corrosion resistance and sulphate resistance of concrete. However, it is necessary that we use flyash conforming to IS specifications in making the concrete. It is very important that the flyash added to cement should be finer than cement particles. Hence, for intimate mixing it is recommended to me mixed in the factory and not at site.

12.5 HIGH-STRENGTH–HIGH PERFORMANCE CONCRETE

High-strength concrete is concrete with strength over 40 N/mm^2. High-performance concrete (HPC) is a new definition recently introduced in concrete technology. High performance concrete is defined as the concrete which will satisfy the special requirements that cannot be achieved by normal concrete. These performances can be high strength, low shrinkage, self compaction, high fire resistance, etc. This is achieved by judicious combination of the materials for such concretes. Normally, to be called high performance concrete the strength of such concrete should be over 60 N/mm^2. Then only it is called HPC. Strengths up to 80 N/mm^2 have been reported. The materials used are the following:

1. Cement
2. Coarse and fine aggregates of required quality
3. Water
4. Supplementary cementing materials like silica fume, flyash, blast furnace slag, etc.
5. Superplasticizers (high water reducing agents)
6. Air entraining agents (optional)

Note: Items 4 and 5 are the special items needed for HPC. This type of concrete is used for special requirements in structural concrete work.

12.6 SILICA FUME CONCRETE

Silica fume is very finely divided silica obtained as a byproduct in industry. Concrete to which silica fume is added is "silica fume concrete". We have seen that normal concrete with normal water-cement ratio always has micropores, which limits the strength of normal concrete. Silica fumes consist of very fine particles (with specific surface about six times that of cement so that it is very much finer than cement particles). Hence, it has been found that if we mix silica fumes with concrete the minute pore spaces can be reduced resulting in high-strength concrete. Silica fume is also a pozzolana which will contribute to the strength. Thus, silica fume along with super plasticizers is a necessary component of high-strength and high-performance concrete.

12.7 POLYMER CONCRETE

The action of SBR latex in cement mortar has been explained in Subsection 10.7. The principle used in polymer concrete is simple. In Chapter 24, polymerization is described as conversion of monomers into polymers. In normal concrete, we have seen that micropores cannot be avoided. The impregnation of monomer into these spaces and subsequent polymerization is the technique that has been developed recently to reduce the porosity of the concrete, to improve its strength and other properties. The following are the four types of polymer concrete materials available at present.

1. Polymer impregnated concrete (PIC)
2. Polymer Portland cement concrete (PPCC)
3. Polymer concrete (PC)
4. Partially-impregnated and surface-coated polymer concrete

These polymer concrete materials can be distinguished as follows:

Polymer impregnated concrete. This type of concrete is ordinary-cured concrete which is dried in an oven and the air in the open cells is removed by vacuum. A low viscosity monomer is introduced into these pores which is then polymerized by application of heat or chemical action or by using radiation.

Polymer Portland cement concrete. This typee of concrete is made by mixing a monomer along with the mixing of cement, aggregate and water. However, the product obtained by this method is not as strong as the impregnated type.

Polymer concrete. Polymer concrete is an aggregate bound with polymer instead of cement. In this process, polymer binder is used instead of cement. It is not a true concrete as used in civil engineering terminology.

Partially impregnated and surface coated concrete. This name is self explanatory.

All these materials at present are mostly used in building construction only for repairs or to improve durability.

12.8 FERRO CEMENT

Ferro cement should not be confused with fibre concrete. Ferro cement consists of closely spaced wiremeshes which are impregnated with rich mix of cement mortar. Usually 0.5 to 1.0 mm diameter steel wires formed into meshes 5 to 10 mm size form the reinforcement. Mortar 1:2 to 1:3 with water-cement ratio 0.4 to 0.45 is poured into the form work with fabricated steel by using layers of the wire-mesh. The steel content of this concrete will be as high as 300 to 500 kg/m^3 of mortar. As the material consists of a large percentage of steel, it has high tensile strength and ductility. The material was developed by the Italian architect P.L. Nervi in 1940 to build a large number of pleasing structural forms.

12.9 READY MIXED CONCRETE (RMC)

As already explained, RMC is a concrete mixed in a centrally located *batching plant* in a factory for the requirements such as slump, grade, pumpability, etc. needed for the work such as for piles or multistoreyed building. The mixed concrete is dispatched in special trucks with rotating drums to the site. This topic is further dealt with in more detail in Section 14.5. Ordinary portland cement is nowadays supplied only to RMC factories. This cement, flyash aggregates and chemicals are mixed to give the necessary type and grade of concrete.

12.10 PRE-PACKED CONCRETE

Generally, concrete is prepared by mixing the ingredients. However, it is also possible to pack the coarse aggregate in the formwork and then fill the voids with specially prepared cement-sand grout so that it will fill all the voids and form a mass of concrete. This type of concrete is called pre-packed concrete. Colcrete is one such process.

This type of construction is used in special situations such as where complex pipework has to be buried in the concrete or where reinforcement placing is very complicated or where a large volume of concrete (like a large machine block foundation) has to concreted without construction joints. One of the chief advantage of pre-packed concrete is that it has very little shrinkage like the normally placed concrete.

12.11 SELF COMPACTING CONCRETE

See Section 14.3(7).

12.12 DURABILITY OF CONCRETE

Durability of concrete is the resistance of the concrete made to deteriorating factors. The major factors that affect durability of concrete are the following:

1. Exposure conditions
2. Type of constituent materials from which concrete is made
3. Cement content (it should not be too little or too much)
4. Water–cement ratio and type of water used
5. Cover to reinforcement
6. Workability or easiness of compaction
7. Shape and size of number
8. Permeability of concrete produced

SUMMARY

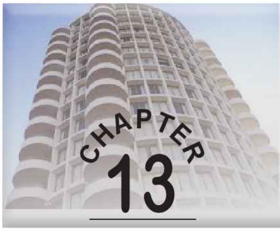
There are many types of special concretes that have been evolved for various types of works. A few of them only has been dealt with in this chapter. They are made by use of the special additives available for the purpose.

REVIEW QUESTIONS

1. What is the difference between High-Performance Concrete (HPC) and High-Strength Concrete? Explain how HPC can be made?
2. Write short notes on the following:
   (a) FRC
   (b) RMC
   (c) Light-weight concrete
   (d) Polymer concrete
   (e) Ferrocement
   (f) Silica fume
3. What is flyash? How can it be used for improving performance of concrete?
4. What is pre-packed concrete? What are its applications?
5. What are the major factors that affect durability of concrete?

REFERENCES

[1] IS 9103–1999: *Admixtures in Concrete Specification.*
[2] IS 4926–2003: *Ready-mixed Concrete Code of Practice.*
[3] IS 4925–2004: *Concrete Batching and Mixing Plants Specification.*



Mix Design of Ordinary Grade Concrete

13.1 INTRODUCTION

Mix design is the process of proportioning the ingredients of concrete with the objectives of producing a concrete with the specified properties like strength, durability and also as economically as possible. Even though by mixing cement, fine aggregate, coarse aggregate and water, we can produce *traditional concrete*, modern concrete is the product of many other additives such as

1. Pozzolanas, silica fumes
2. Chemical additives
3. Fibres, etc.

The mix design incorporating all these materials is a very specialized subject but in this chapter, we will restrict ourselves to the traditional mix design procedure to produce ordinary grade concrete below M40. The *designs of high-strength concrete* of strength higher than 40 N/mm^2 *and the design of high-performance concrete* with strength higher than M60 are special topics which we will not deal with in this chapter. For an economic solution, we should use, as much as possible, locally available aggregates and fit them into the design.

13.2 IMPORTANCE OF WATER-CEMENT RATIO

Even though engineers knew the bad effects of high water content in making concrete soon after the invention of the cement, the law giving the effect of water on strength of concrete was yet to be found. In 1887, Feret formulated the following formula for strength of concrete, which indicated *that lesser the volume of water in the concrete, the greater will be the strength of concrete.*

$$S = K\left(\frac{c}{c+e+a}\right)^2 \qquad (13.1a)$$

where

S = strength of concrete
K = constant
c = volume of cement
e = volume of water and
a = volume of air.

It was as late as 1918, about thirty years later, that Abrams put forth his simple classic law which forms the basis of present day mix design of concrete. It can be stated as follows. The lower the water-cement ratio, the higher is the strength of concrete, provided the mix is workable. The law can be represented by Figure 13.1(a) and it can be expressed mathematically as

$$S = \frac{A}{B^x} \tag{13.1b}$$

where

S = strength

A and B = constants varying with type of cement

x = water-cement ratio by weight

(Figure 13.1(b) is a modification of Figure 13.1(a))

Later, Prof. Lyse found out that the relation between strength and *cement-water ratio* ($1/x$) can be represented by a straight line as shown in Figure 13.1(c). The equation for the strength curve can be written as follows. (Prof. Lyse was also the first HOD of Civil Engineering Department of IIT, Kharagpur).

$$S = K\left(\frac{1}{x}\right) + C \tag{13.1c}$$

where K and C are constants varying with the grades of the cement.

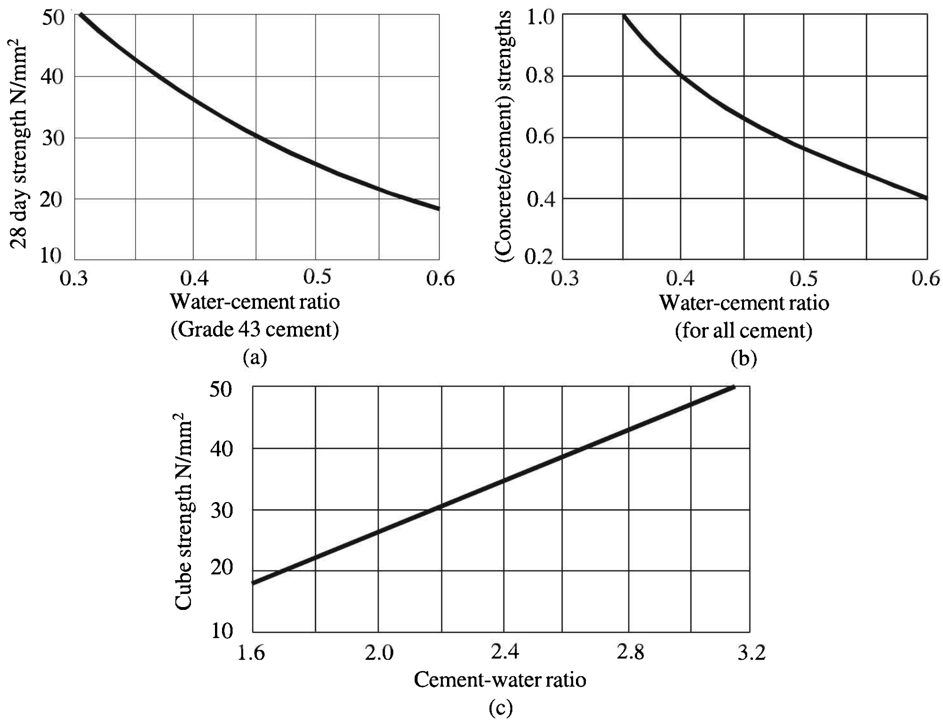


Figure 13.1 28 day cube strength of concrete (a) Abram's law for strength of concrete and w/c ratio (b) Relation between concrete/cement strength and w/c ratio for all types of coments (c) Linear relation between concrete strength and cement/water ratio by Lyse's equation (Refer Sp. 23 Figure 47).

Even though for special concretes like high strength concrete and pumpable concrete, there are many other factors like aggregate cement ratio and size of aggregate that should be taken into account, Abram's law is the main basis for determining the strength of ordinary grade concrete. In this chapter, we will deal only with *mix design of ordinary grade concrete*. Details for design of other types of concrete and special mixes will be studied under the special course in Concrete Technology.

In some of the cases, instead of 28-days strength of concrete, we use 7-days strength. The 7-days strength is roughly 0.75 times the 28-days strength. There are also accelerated tests that are available to predict the 28-days strength of concrete in 24 hours. It consists essentially of boiling the specimen in water or exposing the cube in a steam chamber to accelerate the strength development of concrete. The details of this topic will be covered under the special subject Concrete Technology.

13.3 IMPORTANCE OF QUALITY CONTROL OF CONCRTE

The term *quality control* of concrete refers to the supervision adopted on the site to ensure that the quantity and quality of cement, fine aggregate, coarse aggregate and water is consistent and that the correct proportions of these materials are used in the concrete mix. Statistically, there will always be some variation between the strengths of concrete made at site. However, if good supervision is exercised, then these differences will be small. Hence, a measure of the quality control can be made from the variation of 28-days cube strengths of different batches cast at the site and cured under standard conditions. Broadly, the requirements for the various controls can be summarized as follows:

1. ***Very good control.*** Supervision by experienced concrete technician with field laboratory at site; cement from a single source tested periodically; weigh batching of materials; good control of grading and moisture in aggregates; control of water added and regular slump tests.
2. ***Good control.*** Supervision by experienced concrete technician; carefully stored cement with periodic tests; weigh batching of materials; occasional moisture control of aggregates; controlled water addition and regular slump tests.
3. ***Fair control.*** Proper storage of cement; volume batching of cement; intermittent supervision by concrete-technician; occasional grading and moisture tests as well as slump tests.

The standard deviation of the results of cube test is taken as a measure of the quality control. IS 456 (2000) recommends the following requirements for a *good control* which can easily be exercised at most of the sites:

1. Proper storage of cement
2. Weigh batching of all materials
3. Controlled addition of water
4. Regular checking of all materials for aggregate grading and moisture content
5. Periodical checking of workability and strength.

The standard deviations recommended for good control depend on the grade of concrete and are given in Table 13.1 according to the present R.C. Code IS 456–2000.

For grades 20 and 25, a value of 4 N/mm^2 and for grades 30 to 50, a value of 5 N/mm^2. For lesser controls, we should add at least 1 N/mm^2 to the above values.

13.4 DESIGN OF TRIAL, MIX FOR ORDINARY GRADE CONCRETE BY IS 10262:2009 "CONCRETE MIX PROPORTIONING—GUIDELINES"

The strength of concrete, according to the Indian and British Code of Practice, is the cube strength of 15 cm (6 inch) cubes, cured for 28 days in water at 27°C. It is denoted by f_{ck}. (Smaller cubes will give greater strength and larger cubes lesser strength). The Americans use 6 × 12 inch cylinder strength as standard. It is taken as 0.8 times the cube strength.

Concrete mix design is the method of finding the proportions of water, cement coarse aggregate and fine aggregate to be used to make the concrete. *The earlier IS code IS 10262 of 1982 for design of concrete mix has been revised in 2009 to IS 10262 : 2009 and is called "Guidelines for Concrete Mix Proportioning".* In its foreword, it is also mentioned that this standard does not debar the adoption of any other methods of concrete proportioning. The mix obtained by calculations based on this code should be always tested in the laboratory for assumed strength and workability. The code gives the following tables whose values are based on the tests in the laboratory.

13.4.1 Tables Given by IS 10262 (2009) for Design of Concrete Mixes

There are four tables, i.e., Tables 13.1, 13.2 (A and B), 13.3 and 13.4 (based on laboratory and field test results) to be used for mix design of concrete according to IS 10262: 2009.

Table 13.1 (Table 1 of IS 10262 : 2009) Assumed Standard Deviation for Good Control

Grade of concrete	Assumed standard diviation (N/mm^2)
M10, M15	3.5
M20, M25	4.0
M30, M35, M40, M45, M50, M55	5.0

Notes:

1. **This table gives the standard deviation to be assumed to calculate the cube strength for which the concrete mix is to designed.**

(Contd.)

(*Contd.*)

2. The cube strength for which we should design our concrete mix is called *Target strength*. This must be larger than the cube strength of cement we use in our design of structures called *characteristic strength*. (This is explained in Section 13.4.2.)
3. Target strength = Characteristic strength + k (Assumed standard deviation)
4. If at a site from cube test results the standard deviation according to the work at a given site is found to be different from above, then that value can be used for the design of mixes for that site. For bad control, we have to increase the values of the standard deviation.

Table 13.2A (Table 5 of IS456) Minimum grade, Minimum Cement Content and Maximum Water–Cement (w/c) Ratio Requirement for Plain Concrete Depending on Exposure

Exposure	Minimum grade	Minimum cement content (kg/m^3)	Maximum w/c ratio 0.60
Mild	–	220	–
Moderate	M15	240	0.60
Severe	M20	250	0.50
Very severe	M20	260	0.45
Extreme	M25	280	0.40

Table 13.2B [Table 5 of IS456] Minimum Cement Content, Maximum Water–Cement Ratio and Minimum Grade of Concrete Requirement for Reinforced Concrete Depending on Exposure

Exposure	Minimum cement content (kg/m^3)	Maximum free w/c ratio	Minimum grade of concrete
Mild	300	0.55	M20
Moderate	300	0.50	M25
Severe	320	0.45	M30
Very severe	340	0.45	M35
Extreme	360	0.40	M40

Note: According to IS456, the maximum cement content allowed in concrete is 450 kg/m^3. The Indian railways allows a maximum value = 550 kg/m^3 for its sleepers.

Table 13.3 (Table 2 of IS 10262–2009) Maximum Water Content Allowed per Cubic Metre of Concrete for Nominal Maximum Size of Aggregate (Slump 25 to 50 mm)

Nominal maximum size of aggregate (mm)	Maximum water content (kg)
10	208
20	186
40	165

Notes:

1. *Effect of nature of coarse aggregate.* The above water content values are for angular aggregates. We reduce these values for other aggregates as follows:

(*Contd.*)

(*Contd.*)

(a) Sub-angular aggregates are reduced by 10 kg/m^3.

(b) Gravel with some crushed particles is reduced by 20 kg/m^3.

(c) Round gravel is reduced by 25 kg/m^3.

2. *Effect of increased slump.* The above values are for 25 to 50 mm slump. For increase in required slump, water content is increased by 3% for every additional 25 mm slump.
3. *Use of chemical admixture conforming to IS 9103.* Slump can be increased by addition of chemicals. Hence, with the addition of simple plasticizers, we can decrease the water content by about 5 to 10%. With super plasticizers, we can reduce the water content by about 20%.

Table 13.4 (Table 3 of IS 10262–2009) Volume of Coarse Aggregate Per Unit Volume of Total Aggregates for Fine Aggregates Conforming to Different Zones (Zones I to IV Coarser to Finer) for Water Cement Ratio of 0.50

Maximum size of aggregate (mm)	Volume of coarse aggregate per unit volume of total aggregate for different zones of fine aggregate			
	Zone 4	Zone 3	Zone 2	Zone 1
10	0.50	0.48	0.46	0.44
20	0.66	0.64	0.62	0.60
40	0.75	0.73	0.71	0.69

Notes:

1. Zone 4 is fine sand and zone 1 is coarse sand (see Figure 7.1).
2. (See Section A7 of Annexure 7 of code) IS 10262: 2009.
3. The value of volumes of coarse aggregate given in Table 13.4 is for w/c ratio of 0.50. In case, the water–cement ratio arrived at is lesser than this value, there should be lesser fine aggregate, and hence, the volume of coarse aggregate has to be increased. Hence, for change in water-cement ratio from 0.50, we follow the following rules:
   (a) For every decrease of 0.05 in water–cement ratio from 0.5, we increase the proportion of volume of coarse aggregate, as given in Table 13.4, by 0.01.
   (b) For every increase of 0.05 of water–cement ratio, we decrease the proportion of volume of coarse by aggregate, as given in Table 13.4, by 0.01.

Example 13.1 Find the percentage of coarse aggregate for a derived water–cement ratio of 0.4 for 20 mm aggregates with zone 4 fine aggregate, given that the percentage of coarse aggregate for water–cement ratio of 0.50 is 0.66, as given in Table 13.4.

Solution: For w/c of ratio 0.40, increase in percentage of coarse aggregate = 0.66 + 0.02 = 0.68.

For pumpable concrete. For this type of concrete, the amount of coarse aggregate shown in Table 13.4 is to be reduced by 10%.

13.4.2 Step by Step Procedure for Traditional Mix Design of Ordinary Concrete according to IS 10262: 2009

The following step by step procedure is recommended to find the mix proportions for ordinary concrete for one cubic metre of traditional concrete.

Step 1—Find target strength

Target mean compressive strength is the strength for which we design our concrete mix. From statistics, we have (with k, the constant from statistics)

Target strength = Characteristic strength + k (Standard deviation)

For not more than 5% of samples not to fall below mean value, the value of k from theory of statistics is 1.65. Hence, with standard deviation represented as s.

$$F_{ck} = f_{ck} + 1.65 \times s$$

where F_{ck} is design strength.

For good control, standard division s can be assumed as 4 N/mm^2 (Table 13.1).

Hence, design strength $F_{ck} = f_{ck} + 1.65 \times 4$

Step 2—Assume a w/c ratio

The relationship between strength and free water-cement ratio depends on many factors such as the property of cement, size aggregates, its grading, etc. Hence, unless we establish a value from tests for the materials we are using, we have to assume a value. Assume the water–cement ratio for the specified strength from experience or from test results (such as Figure 13.1).

Step 3—Select total water content

From Table 13.3, find the value of maximum volume of water in kilogramme per cubic metre of concrete for 25 mm slump. If the slump required is more, modify the given slump as given in the notes below Table 13.3. (Remember the magnitude. In Table 13.3, for 20 mm aggregate, the water required is 186 kg/m^3 of concrete.)

Step 4—Find weight of cement required

From steps 2 and 3, we get

$$\text{Weight of cement} = \frac{\text{Weight of water to be used}}{\text{w/c ratio}}$$

Check the cement content with minimum, as specified in IS 456 in Table 13.2B.

Step 5—Calculate total volume of cement and water (assume specific gravity of cement = 3.15)

$$\text{Volume of cement} = \frac{\text{Weight of cement}}{3150}\,\text{m}^3$$

$$\text{Volume of water} = \frac{\text{Weight of water}}{1000}\,\text{m}^3$$

Let the volume of total water + cement volume be V_1.

Step 6—Find balance of one cubic metre volume (This is occupied by aggregates.)

For unit volume balance = $1 - V_1 = V_2$. This is occupied by coarse and fine aggregates.

Step 7—Find the volume and then the weight of coarse aggregate

Volume $V_3 = V_2 \times$ Percentage of coarse aggregate from Table 13.4.

Weight = Volume × Unit weight

Step 8—Find volume and weight of fine aggregate

Volume of fine aggregate $V_4 = V_2 - V_3$

Weight of fine aggregate = Volume × Unit weight per cubic metre

Results

From the above calculations, we get the following values for one cubic metre of concrete of the mix.

1. Weight of water for the mix
2. Weight of cement required
3. Volume and weight of coarse aggregate required
4. Volume and weight of fine aggregate required

Notes:

1. The above result gives mix proportion for one cubic metre of concrete from which we can calculate the proportions for a bag of cement weighing 50 kg and 35 litres in volume.
2. *Effect of introduction of water-reducing admixtures (plasticizers) and superplasticizers conforming to IS 9103*. This usually decreases the water needed by 5 to 10% and 20%, respectively. The addition is usually 2% of the weight of cement. The specific gravity of these admixtures is taken as 1.145.
3. *Placing concrete by pumping*. For many works concrete may have to be placed by pumping from a control mixing unit. In that case, the value of coarse aggregate should be reduced by 10%. In addition, superplasticizers also must be added at the rate of 2% by mass of cementitous materials.
4. *Self-compacting concrete*. The designs of these special concrete mixes are described in books on "Design of Concrete Mixes".

13.4.3 Application of the Code

It should be noted that the new IS code, in its foreword, says that this standard does not debar the application of any other methods of concrete mix proportioning that the site has successfully used. The present code is based on AC1211.1 "Standard Practice for Selecting Proportions for Normal Heavy Weight and Mass Concrete" of the American Concrete Institute.

Example 13.2 **Design a concrete mix of the following requirements by new IS code. Also compare those values with values got by old IS code**

Required characteristic compressive strength = 20 N/mm^2 (M 20) and slump 70 mm with the following materials:

1. Type of cement: OPC 43 grade; Specific gravity 3.15
2. Type of the coarse aggregate: Crushed stone 20 mm (maximum size) with specific gravity 2.68

3. Type of fine aggregate: Zone 1 – Sand with specific gravity 2.65 (see Chapter 7)
4. Exposure: Mild; No chemicals are to be added to the mix.

Calculate the quantities for a trial mix for one cubic metre of concrete and one bag of cement.

(***Note:*** As this book is mainly intended for beginners, we will not introduce effect of superplasticizers on mix design, method of placing concrete by pumping (increasing flow of concrete), etc. here

Solution: Table 13.5 gives the solution to the above problem.

Table 13.5 Steps and Calculations

Steps	Calculations
1.	*Find target mean strength* $F_{ck} = f_{ck} + 1.65 \times s$ (Assume s = 4 N/mm^2—Good control) F_{ck} = 20 + 1.65 × 4 = 26.64 N/mm^2 (cube strength)
2.	*Assume w/c ratio and check it with Table 13.2B (IS456)* From experience, we assume w/c ratio = 0.5 (We may also use diagrams like Figure 13.1 or other data for this.) Now, we check the maximum value in Table 13.2B. w/c ratio = 0.55. Hence, it is correct.
3.	*Find the maximum weight of water per cubic metre allowed (as shown in Table 13.3) for 25 mm slump* For 20 mm aggregate, maximum water content = 186 kg/m^3 for 25 to 50 mm slump For 75 mm slump (additional 50 mm slump = 186 +(3/100) × 186/m^3 = 191.6 kilogramme of water per cubic metre of concrete (see note 2 below Table 13.3) (We increase 3% for every additional 25 mm slump.)
4.	Calculate the weight of cement per cubic metre of concrete for the mix and check whether the value is larger than that given in IS456. Water to be used = 191.6 kilogramme per cubic metre of concrete ∴ Weight of cement per cubic metre of concrete with w/c ratio = 0.5 We check value with IS456 (Table 13.2B). It should not be less than 300 kg/m^3. Hence, it is correct.
5.	*Find the volume of cement and water in one cubic metre of concrete* Density of cement = 3150 kg/m^3 Volume of 383 kg of cement = $\frac{383}{3150}$ = 0.121 m^3 Volume of 191.6 kg of water = 0.1916 m^3 Total volume of water and cement = 0.3126 m^3
6.	*Find the balance volume of one cubic metre occupied by coarse and fine aggregates* Volume of all aggregates = 1 – 0.3126 = 0.6874 m^3
7.	*Find the volume of coarse aggregate for zone I of fine aggregate by using Table 13.4 and its weight* (***Note:*** As w/c ratio is 0.5, no correction in volume of coarse aggregate value of table in needed. Otherwise, for every decrease of 0.05 from 0.5 of water–cement ratio, we increase the ratio of coarse aggregate by 0.01. From Table 13.4, volume of coarse aggregate for 20 mm maximum size and zone 1 fine aggregate is 0.60 of the total. Volume of coarse aggregate = 0.6874 × 0.6 = 0.412 m^3 Weight with specific gravity 2.68 = 0.412 × 2680 = 1105 kg
8.	*Find the volume and weight of fine aggregate and its weight* Volume fine aggregate = 0.6874 × 0.4 = 0.274 m^3 Weight with specific gravity 2.65 = 0.274 × 2650 = 726 kg

(Contd.)

(*Contd.*)

9. *Find mix proportions for trial mix for one cubic metre of concrete*

Cement = 383 kg

(Number of bags per cubic metre of concrete = $\frac{383}{50} = 7.66$ bags

Water = 191.6 kg
Weight of coarse aggregate = 1105 kg
Weight of fine aggregate = 726 kg
Water–cement ratio = 0.5

10. *Find mix proportions for one bag of cement*

	New code	Old code (From page 118)
Cement	50 kg	50 kg
Water	25 kg	25 kg
Coarse aggregate	$\frac{1105}{383} \times 50 = 144.25$ kg	158 kg
Fine aggregate	$\frac{726}{383} \times 50 = 94.7$ kg	78 kg
Total weight	**313.95 kg**	**311 kg**

(Note use of the new code results in more sandy concrete)

11. Calculate the yield of concrete per bag cement and also the number of bags of cement per cubic metre of concrete

Yield for 383 kg of cement is one cubic metre of concrete as obtained from step 9

Hence, yield for 50 kg (one bag) = $\frac{1 \times 50}{383} = 0.130\ m^3$

(Bags of cement for one cubic metre of concrete = $\frac{383}{50} = 7.66$ bags)

Notes:

1. In actual practice, we use dry aggregate. The above mix design is for aggregates that are wet, but their surface is dry. Hence, the water content value must be corrected for actual conditions.
2. Annexure B of the code gives an example of mix design using fly ash admixture.

13.4.4 Relation between Slump and Compaction Factor

The workability of concrete is sometimes specified by another test called *compaction factor*. In this test, the freshly cast concrete is allowed to fall from one cone to another at a lower level and the compactor produced is measured. The relation between slump and compacting factor is shown (roughly) in Table 13.6 below:

Table 13.6 Relation between Slump and Compacting Factor

Workability	Slump (mm)	Compaction factor
Very stiff	–	0.70
Stiff	0 to 25	0.75
Stiff plastic	25 to 50	0.85
Plastic	75 to 100	0.90
Flowing	150 to 175	0.95

13.5 NEED FOR TRIAL MIX AND STRENGTH TESTS IN THE LABORATORY

Theoretically, mix design for ordinary grade concrete can easily be carried out by the steps discussed in Section 13.4 on the data IS 10262 or SP 23. After calculation of the required mix, we proceed for a trial mix in the laboratory as follows:

1. In all the cases, the data obtained by theory has to be tested by a trial mix. Adjustments have to be made in the final proportions by looking at the "feel of the concrete in the laboratory" as tested by means of running a trowel over the mixed concrete or by specified laboratory tests on fresh concrete. Slump test is also carried out. The quantity of sand, cement and water are adjusted by carrying out a trial mix to get a workable concrete with the required water-cement ratio.
2. Cube tests are then carried out and a laboratory report along specified lines has to be given before the mix is accepted for use in the field.

13.6 FINENESS MODULUS

The American method of mix design uses the fineness modulus (F.M.) method. F.M. is used to indicate roughly the average size of the particles of the entire quantity of aggregate. It is defined as follows:

$$\text{F.M.} = \frac{\text{Sum of percentage retained on ten standard sieves}}{100}$$

The specified sieves are 80 mm, 40 mm, 20 mm, 10 mm and B.S. sieves 480, 240, 120, 60, 30 and 15. (All the ten sieves are used for mixed aggregate—the first four for coarse aggregate only and the last six for fine aggregate only.)

It is recommended that the fineness modulus of fine aggregates should be 2 to 3.5. The larger the F.M., the coarser will be the aggregate.

13.7 THUMB RULE FOR YIELD OF CONCRETE

As we have seen, the volume of concrete obtained from one bag of cement is called yield of concrete. Its exact value can be calculated by absolute volume as shown in step 10 of Example 13.2.

A thumb rule used to find the yield per bag of cement when using the usual volume mix is the following.

Yield per bag = 2/3 (Volume of the components)

(We may also assume one bag of cement is 35 litres or 0.035 cubic metre) in loose volume

Thus, for 1 : 2 : 4 concrete, we get

Yield per bag = $= \frac{2}{3} \times (0.035)\,(1+2+4)$ = 0.16 m^3

Number of bags per cubic metre concrete = $= \frac{1}{0.16} = 6.3$

Weight of cement per cubic metre of concrete = 6.3 × 50 = 315 kg.

13.8 CLASSIFICATION OF EXPOSURE CONDITIONS

Tables 13.2A and 13.2B give values of grade, water–cement ratio to be used for different exposure conditions. The exposure conditions are classified as mild, moderate severe, very severe, and extreme (5 divisions). The following is the description of these conditions:

1. ***Mild.*** Concrete surface protected against weather and aggressive conditions and not in coastal areas.
2. ***Moderate.*** The concrete surfaces:
   (a) sheltered from rain
   (b) exposed to condensation and rain
   (c) continually under water
   (d) buried under non-aggressive soil or groundwater
   (e) sheltered from saturated salt air in coastal areas
3. ***Severe.*** The concrete surfaces:
   (a) exposed to severe rain, alternate wetting and drying
   (b) completely immersed in sea water
   (c) exposed to coastal environment
4. ***Very severe.*** Concrete surface exposed to sea water spray, corrosive fumes
5. ***Extreme.*** The concrete surfaces of
   (a) members in tidal zone
   (b) members in direct contact with liquid or solid aggressive chemicals.

SUMMARY

For structural use, concrete is specified by its strength and also by specifying a limiting water–cement ratio as well as the minimum cement content. The last two requirements are for assurance of durability. For these given data, we can design the proportions of cement, aggregates and water to be used for a given strength of concrete. This is called mix design. Indian Standards, IS 10262 and SP23 deal with the method to be used for mix design of ordinary concrete.

Example 13.3 **Concrete Mix Design by Old Code IS 10262–1982**

Design a concrete mix of characteristic strength 20 N/mm^2 (M20) using C43 grade cement, coarse aggregate of maximum size 20 mm for a slump of 30 mm. Assume that the field control is good. Also assume that specific gravity of coarse and fine aggregates is 2.60 and that of cement is 3.15. Coarse aggregate is crushed stone and sand conforming to Zone II is used for the construction.

Steps	*Calculations*
1	*Find target mean strength* $f_{ck} = f_{ck} + 1.65s$ (For good control s = 4 N/mm^2, see Section 13.3) $= 20 + 1.64 \times 4 = 26.6$ N/mm^2

2 *Select water-cement ratio for above strength*

From Figure 13.1(a), for f_{ck} = 26.6; w/c = 0.50 (approx.)

Also $\frac{M_{20}}{C_{43}} = \frac{26.6}{43} = 0.62$; w/c ratio = 0.50, using Figure 13.1(b)

This does not exceed 0.55 as specified in IS 456–2000

3 *Select total water per cubic metre of concrete = W*

From Table 13.3, for 20 mm aggregate, we get W = 186 kg/cm^3

4 *Select percentage of sand required*

As per IS code, for 20 mm aggregate, *percentage of sand r = 35%* = 0.35 (We can also assume any value between 30 to 40%)

5 *Make adjustment in water and sand percentage for difference in w/c ratio from 0.6 and Zone II sand by table in the code*

No adjustment is needed for (a) zone of sand, (b) workability and (c) for type of aggregate with reference to the table. We need adjustment only for change of w/c ratio from 0.6 to 0.5.

Adjustment in sand content. Change in w/c ratio = 0.6 to 0.5 = 0.1

Change in r for each ± 0.05% = ±1%. Hence for –0.1 w/c; change = –2%.

New value of r = 0.35 – 0.02 = 0.33.

6 *Determine cement content*

$$\text{Cement per m}^3 = \frac{\text{Water required}}{\text{w/c ratio}} = \frac{186}{0.50} = 372 \text{ kg/m}^3$$

This is more than the minimum of 300 and less than the maximum 450 kg/m^3 specified in IS 456.

7 *Determine weights of coarse and fine aggregates required*

Assume 2% air; volume of concrete is 980 cc. Calculate absolute volume

$$980 = W + \frac{C}{c} + \frac{1}{r}\left(\frac{F_a}{S_f}\right)$$

$$= 186 + \frac{372}{3.15} + \frac{1}{0.33}\left(\frac{F_a}{2.60}\right)$$

Weight of fine aggregates, F_a = 580 kg

Weight of coarse and fine aggregates together $= \frac{580}{0.33} = 1757$ kg

Weight of coarse aggregate = 1757 – 580 = 1177 kg

8 *Calculate the weight of each material per bag of cement (50 kg) (for weigh batching.*

Cement = 50 kg (w/c ratio 0.5 from step 2)

Water = 50 × 0.5 = 25 kg (litres)

Steps	*Calculations*
	Sand $=\dfrac{580}{372}\times 50 = 78$ kg (From steps 6 and 7)
	Crushed tone $\dfrac{1177}{372}\times 50 = 158$ kg (From steps 6 and 7)
	Total weight = 50 + 580 + 78 + 158 = 311 kg
	Note: In actual practice, the water content should be corrected for absorption of water by coarse aggregate and sand.
9	*Calculate yield of concrete per bag of cement (solid volumes)*
	Cement $=\dfrac{50}{3.15} = 15.8$ litres (solid volume)
	Fine aggregate $=\dfrac{78}{2.6} = 30$ litres
	Coarse aggregate $=\dfrac{158}{2.6} = 60.7$ litres
	Water = 25 litres
	Total volume = 15.8 + 30 + 60.7 + 25 = 131.5 litres
	Air 2% (assumed) $=\dfrac{2\times 131.5}{100} = 2.6$ litres
	Grand total = 134.1 litres = 0.134 m^3 = yield per bag of concrete
	Density of concrete $=\dfrac{31.10}{0.134\times 1000} = 23.2\ \text{kN/m}^3$
	Yield per bag of cement = 0.134 m^3 of concrete
	No. of bags of cement per cubic metre of concrete $=\dfrac{1}{0.134} = 7.46$ bags

REVIEW QUESTIONS

1. What is meant by mix design of concrete? Indicate the mix design procedure recommended by IS 10262 (2009). Is this method applicable to high strength concrete? Is it obligatory to use this code in all works?

2. Design a concrete mix for Grade M20 concrete using Grade 43 cement and Zone II sand with good field control. Assume that the relation between concrete strength and water–cement ratio is given by the following (Lyse's equation for Grade 43 cement).

Cube strength $=\dfrac{22}{x} - 15$ (where x = Water–cement ratio)

3. Write short notes on
   (a) Solid volume
   (b) Target strength and characteristic strength
   (c) Standard deviation for field control
   (d) Field control of concrete.

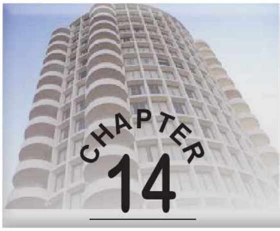
4. Is it compulsory or optional to use the new IS code 10262–2009 for all concrete works.

REFERENCES

[1] IS 10262–2009: *Concrete Mix Proportioning—Guidelines* (old code drafted in 1982 has been revised in 2009).

[2] SP 23–1982: *Handbook on Concrete Mixes (Based on Indian Standard).*

[3] IS 456–2000: *Plain and Reinforced Concrete—Code of Practice.*



Concrete Construction and Repair Chemicals—Readymixed Concrete

14.1 INTRODUCTION

Nowadays, concrete is used for many purposes. In many construction sites, we have to modify its nature to suit the circumstances. For example, we may have a situation where we have to increase the workability without decreasing its strength and produce self competing concrete. We may have another situation where we have to retard or accelerate the setting time. We may have to make it rock hard in a very short time, to plug a leakage. There are yet other situations as in concrete water tanks where we want waterproof the concrete. Special chemicals are being manufactured that can be added to the concrete for these purposes. In this chapter, we will briefly deal with some of them. Another practice that is becoming prevalent in our major cities is the use of mixed concrete delivered at site of work in special trucks in rotating drums. This is called Readymixed Concrete (RMC). In this chapter, we will also deal briefly with the concrete chemicals used for these purposes.

14.2 CONCRETE CHEMICALS

Chemicals used in concrete construction and repair can be divided into three groups as follows:

1. ***Admixtures to concrete.*** These are the chemicals added to concrete at time of *mixing to get the required properties*. The most popular ones are as follows:
   (a) Water-reducing agents (Plasticizers)
   (b) Set-retarding agents
   (c) Set accelerators
   (d) Combination chemicals
   (e) Waterproofing admixtures
   (f) Air-entraining agents

   These admixtures are briefly dealt with in this chapter.
2. ***Concrete repair chemicals.*** These chemicals are of recent origin and are mainly used for repair work as well as in construction work. The following are the main types:
   (a) Epoxies (Epoxy resin and hardener)
   (b) Polymers and latex bonding chemicals
   (c) Acrylic polymers
   (d) Polyester resions

3. ***Construction chemicals.*** There are many chemicals used as aids in the *construction industry* for various purposes. Some of them are the following:
   (a) Mould-releasing agents
   (b) Concrete-curing compounds
   (c) Bonding aid for plastering

A good reference for a detailed study of this subject is the publication by CPWD "Handbook on Repair and Rehabilitation of R.C. buildings". Appendix 5.1 entitled "Product Guide on Construction and Repair Chemicals".

We will briefly deal with these three groups in the subsequent sections.

14.3 CEMENT AND CONCRETE ADMIXTURES

The important concrete admixtures are the following:

1. ***Water-reducing agents.*** It is explained in Chapter 13 that a certain amount of water per cubic metre of concrete is required for a given workability. If we want to increase the workability, then we have to add more water which will either increase the water-cement ratio with the same cement content or increase the cement content with the same water-cement ratio. Instead of adding extra water, we can add the water-reducing admixtures which will give greater workability to the concrete. *It disperses the cement particles and makes concrete more workable*. They are classified into two groups.
   (a) *Plasticizers.* These chemicals were the first to be introduced for the above purpose. They are organic or combination of organic and inorganic substances. One of the common chemicals used is Lignosulphonic acid in the form of either its calcium or sodium salt (LS). These chemicals are comparatively cheap in price. They reduce the water requirement 8 to 15 per cent.
   (b) *Superplasticizers.* These are chemicals which will decrease the water requirement for a given workability more than plasticizers, by more than 15%. They can reduce the water requirement even upto 30 per cent. These chemicals are costly; and as all superplasticizers do not match all types of cement, trial mixes must be made before a given chemical is used at the site.

   In all high strength concrete production, super plasticizers have to be used to reduce the water-cement ratio. They are used by some companies in readymixed concrete also. More information on the subject can be obtained from books on Concrete Technology.

2. ***Retarders.*** In readymixed concrete, the required concrete is manufactured in a properly located batching plant exercising very good control. Batching plants are usually located away from the city centre where most of the readymixed concrete is used. After mixing, concrete is discharged into special trucks with rotating drums and transported long distances so that the concrete will reach the site after considerable time after mixing at the factory. Under these circumstances, the setting has to be delayed or retarded, so that at the site it is in a plastic state. In such situations, set- retarding agents are used. Retards are also used in many other situations like where we have to obtain exposed aggregate surface in concrete. The retarder is sprayed on the formwork facing the part

meant for exposing the aggregate so that after the main part of the concrete has set, that face can be treated with a water jet to wash off the unset cement and thus, expose the aggregates.

The most commonly used chemical as retarder is *calcium sulphate*. Common sugar, if added in dose of 0.2 per cent, also retards setting of cement up to 72 hours.

3. ***Set accelerators.*** Set accelerators are the substances added to concrete to accelerate setting of concrete. Some of them are so active that a "stonehard concrete" can be obtained in about two minutes. When cement is mixed with silicate (available in the market in consistency of honey) to form into the consistency of a putty, it can be pushed into crevices to stop leakages as the mix sets hard in about 2 minutes. The product by trade name *aquarigid* available in the market is one such substance. A field trial must always be conducted when using these materials.

4. ***Combination chemicals.*** Chemicals with combination of the above properties are available in the market as listed below:
   (a) Retarding superplasticizers
   (b) Accelerating superplasticizers
   (c) Retarding plasticizers
   (d) Accelerating plasticizers.

5. ***Waterproofing admixture.*** Waterproofing admixtures are the chemicals which we can add to cement mortars or to concrete mixes to make them waterproof. Concrete is porous due to the presence of water in excess of that required for hydration of cement. This water tends to form capillary pores in the hardened concrete. Some of these chemicals when added to concrete or cement mortar are meant to cause contraction of capillaries. Some chemicals are meant to form crystallization products and block the capillary. Others convert the water-absorbing capillary forces into water-repelling capillary forces due to the hydrophobic (tendency to repel-water) effect of the chemical constituents. They are available either in the powder form or in the liquid form. They are also mixed in cement mortar to form waterproof mortar. The following are some of the popular dampproofers popular in India:
   (a) *Aquaproof.* It is a white powder to be mixed at 1 kg per bag of cement. It increases impermeability of concrete.
   (b) *Cico.* Cico No 1 is one of the very popular waterproofing additive to cement. It is a colourless paste to be mixed at 3 kg of Cico to 100 kg of cement (3%). The paste is dissolved in the concrete mixing water and used for making concrete. (Cico company produces many chemicals for different purposes.)
   (c) *Impermo.* This is also a waterproofing compound added to cement to make it impervious.

   There are many other products marketed by companies manufacturing concrete chemicals.

6. ***Air-entraining agents.*** Perhaps, the first concrete admixture used in concrete is the air-entraining agent. It was discovered around 1930. These agents incorporate millions of stable isolated air bubbles in concrete. Such concrete has been found to resist action

of frost much better than ordinary concrete. As it also increases workability, it was used in India on many projects before the advent of plasticizers to increase workability of concrete. At present, as cold weather is not a problem in most parts of India, it is not very popular in India. The materials used as air-entraining agents are natural wood resins, animal and vegetable oils, sulphonated organic compounds, etc.

7. ***Chemicals to produce self-compacting concrete.*** These produce concrete that can fill the formwork like a liquid without use of vibrators. In places where the steel placement is so close, these can be used for placing concrete without using vibrators.

14.4 CONCRETE REPAIR CHEMICALS

We will briefly deal with the common repair chemicals here.

1. ***Epoxy resin and hardeners.*** The first chemicals that were developed for repair were epoxy resin and hardener to make it harden. Resin is the adhesive substance secreted by plants. Methods have been found to make it in a chemical plant by chemical process. For hardening of the product, we need a separate chemical called hardener.

   This is the common M seal we get in automobile shops for repair of leakage in radiators, joining broken parts, etc. The resin base and hardener are mixed together and used for repair. The mixture sets in about ninety minutes and joins the broken parts. However, this is costly and needs experience to use it.

2. ***Polymer latex.*** Natural rubber is a polymer (combination of monomers) made by the rubber tree. Many similar compounds are available as repair chemicals. The action of there chemicals is to fill the capillary pores in concrete that exist due to the excess water we add for workability, and thus, they make the resultant concrete a solid mass.

3. ***Some repair chemicals available in the market.*** The following are same of the repair chemicals available in the market:
   (a) Injection grouts
   (b) Rust removers for reinforcements
   (c) Corrosion inhibitors
   (d) Bonding coats for reinforcements
   (e) Bonding coats for both concrete and reinforcement.

   Study of concrete repair chemical is a vast and interesting subject. There are many firms in this business and extreme care should be taken to choose the chemicals to be used as many brands do not come up to the standard. Its use should be based on the experience of using it before.

14.4.1 An Example of Use of Repair Chemicals

Let us take the example of repair of an old R.C. roof slab with bottom falling off due to steel corrosion we proceed as follows:

Clean the reinforcement thoroughly using *rust remover*, if there is too much rust (add extra steel, if needed). Clean the concrete surface. Apply *anticorrosive point to steel*, add *bonding* *coat* to old concrete surface and steel. Apply *polymer modified mortar* before the bond coat dries up. After setting of concrete, cure the repaired surface at least for seven days.

Bonding coat is also used as a construction chemical to be applied before plastering the underside of newly constructed roof and floor slabs. (The old practice of hacking cannot nowadays be done properly by labour.)

14.5 CONSTRUCTION CHEMICALS

In this section, we will give a brief account of some of the construction chemicals.

1. ***Mould-releasing agents.*** For easy release of the moulds (shuttering) from hardened concrete, it was the practice to apply materials such as burnt engine oil, crude oil, etc. on the shuttering before concreting. (They are still used as they are very low in cost.) These mould releasing oils do not leave a good surface for subsequent plastering. Nowadays, we have specially formulated efficient substances for this purpose. Separate materials are available for timber, plywood, steel, etc.
2. ***Concrete-curing compounds.*** Where it is difficult to cure concrete by water, we may coat the moist concrete surface with curing compounds so that the moisture in the concrete is retained for the concrete to get cured. They usually get peeled off after 28 days. Most of them are fully efficient only for 24 hours, reducing in efficiency to about 60% in 14 days. Usually, they consist of synthetic resins, wax, chlorinated rubber, etc.
3. ***Bonding aids for plastering of concrete.*** The traditional method for plastering a cast concrete surface like the underside of a concrete floor (ceiling) is to hack the surface to form a key between the structure and the plaster. This is especially necessary when we use mould-releasing oils. Liquid polymer bond aids in ready-to-use form are now available for this purpose. Plastering should be carried out as early as possible within a waiting period of 60 to 90 minutes after the application of this bonding agents. Most of them are latex based.

14.6 READYMIXED CONCRETE

In the major cities in India, for construction in congested places, it is difficult to find space for storing aggregates and mixing concrete at the site. Also in many cases, it is difficult to lift the concrete to large height by employing manual labour. Employing and managing a very large team of labourers is very difficult. Moreover, the work by labour is very slow and time consuming. If a work such as a machine foundation has to be cast continuously without construction joints, then we have to work continuously during day and night if we employ labour. In such cases, concrete can be placed by concrete pumps very fast and with ease. Pumpable concrete has to be produced using designed mix and additives. Many companies have started readymix plants located away from the centre of the city where concrete can be mixed by using batching plants. Any concrete required can be designed and mixed here by these plants to specific requirements of strength workability, pumpability, etc. The transporting trucks being heavy, delivery can be made in places where there are good roads. In city neighbourhoods, where the roads are meant to take only light loads, these trucks can damage the roads and give trouble.

As the batching plants are located at large distances from the site of work, the concrete has to be transported to the site in special trucks with rotating drums. The concrete mixed at the plant is dosed with retarding agents and discharged into these drums. The drums rest inclined more or less horizontally on the trucks and rotate continuously and slowly so that the concrete is kept agitated all along the journey. This prevents premature setting of concrete and concrete is delivered at the site in the plastic condition. The drums can be tilted to discharge their contents at the site to the pumps to be pumped to the exact place required.

Most of the readymix concrete is placed by concrete pumps, which are pumps specially designed for lifting concrete to large heights (up to 400 m) and large horizontal distances (up to 2000 m). In such cases, we design the concrete by the principles for "design of pumpable concrete" which can flow through a pipe without segregation. Readymixed pumpable concrete is used today in most of the multistoreyed building constructions in the major cities in India. The owners of the readymixed plants also give the necessary concrete pumps on hire. However, it has been found in practice that while ordering readymix concrete, we have to make a very good estimated of the quantity required to complete the work satisfactorily.

SUMMARY

Concrete admixtures form an important class of modern construction material. It is an essential component in production of high-strength, self-compacting readymixed and pumpable concretes. Readymixed pumpable concrete is becoming more and more popular in all the principal cities of India. In addition there are many other construction chemicals like mould reliasing agents we use in the construction industry.

REVIEW QUESTIONS

1. Name four commonly used *concrete chemicals* that we use as admixtures to concrete to modify their properties. Explain their action and use.
2. Name three commonly used *construction chemicals* used as aids in concrete construction and explain their use.
3. Write short notes on:
   (a) Superplasticizers and plasticizers
   (b) Readymixed concrete
   (c) Pumpable concrete
   (d) Concrete-curing compounds
   (e) Polymer-bonding agents.

REFERENCES

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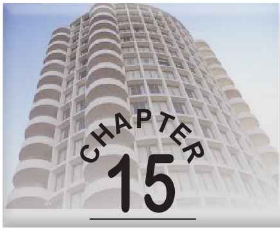
[2] IS 4926–2003: *Readymixed Concrete—Code of Practice.*

[3] *Repair and Rehabilitation of Buildings CPWD,* New Delhi, 2002.



CHAPTER 15

Timber

15.1 INTRODUCTION

The products of wood from felled trees suitable for construction purposes are called timber. Trees meant for timber for buildings should be felled as soon as possible after reaching maturity. Prematurely felled trees contain excess sapwood. The best time to fell trees for timber is midsummer or midwinter when the movement of sap in the wood is the minimum. Timber from overaged trees is brittle and the central portion of the tree will have cavities. In this chapter, we will deal with the main points to be considered in the selection of timber for construction of buildings.

15.2 CLASSIFICATION OF TREES AND STRUCTURE OF WOOD

We will first briefly study the classification of trees and structure of wood.

15.2.1 Classification of Trees

Trees are classified as endogenous (growing by addition of tissues inwards like palms, bamboos, etc.) and exogenous (growing by addition of new tissues outwards). Timber used in building industry belong to this second group. They are further divided into the following two divisions.

1. ***Softwood*** such as pines and spruces which have needle-like leaves, also known as conifers as they bear cone-shaped fruits. They also show distinct annual rings. In pines, resins are present in pores.
2. ***Hardwood*** which are mostly broad-leafed trees. They are deciduous trees, which shed their leaves annually.

A comparison of softwood and hardwood is shown in Table 15.1.

Table 15.1 Comparison of Hard and Soft Woods

No.	Property	Hardwood	Softwood
1.	Annual rings	Not distinct	Distinct
2.	Colour	Dark	Light
3.	Density	High	Low
4.	Modullary rays	Distinct	Not distinct
5.	Strength	Strong in tension, compression and shear	Strong in tension but weak in shear
6.	Examples	Teak, sal	Fir, pines

15.2.2 Structure of Wood

The growth of a tree is shown in Figure 15.1 and the cross section of a trunk of a tree is shown in Figure 15.2. The *outer bark* is like our skin. It protects the tree from extremes of temperature, mechanical damage, etc. The *inner bark* called bast is softer and more moist than the outer bark. It also conducts the sap produced in the leaves to all the areas of active growth and on into the places of storage. Moisture from the ground moves up in the *sapwood* which is

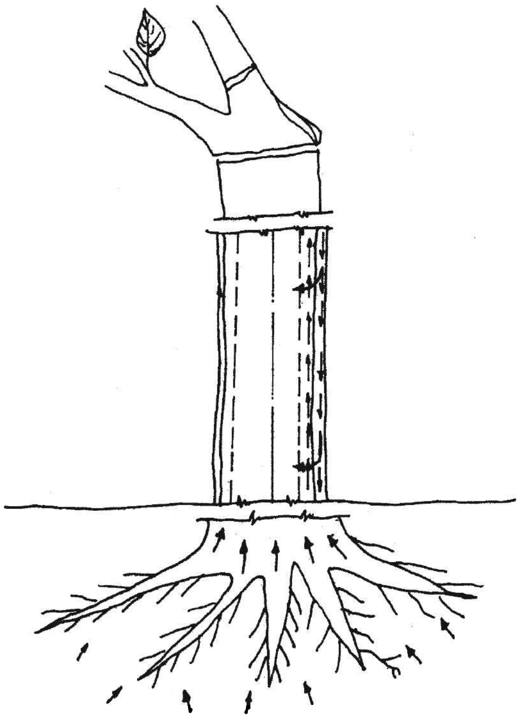


Figure 15.1 Growth of a tree.

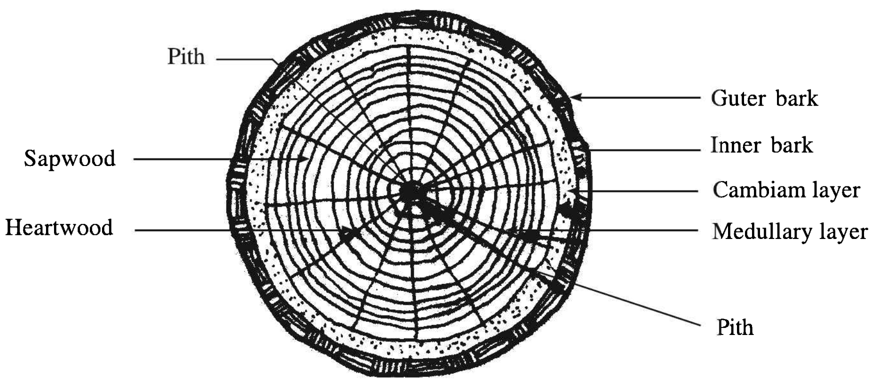


Figure 15.2 Cross section of an exogenous tree.

immediately under the inner bark. The nature of growth of the *exogenous trees* (like conifers and deciduous trees) is to lay down each growing season a new layer of tissues (cells) outwards forming a conical sheath from top to bottom. They form the growth rings. In endogeneous tress like bamboo the growth is inwards.

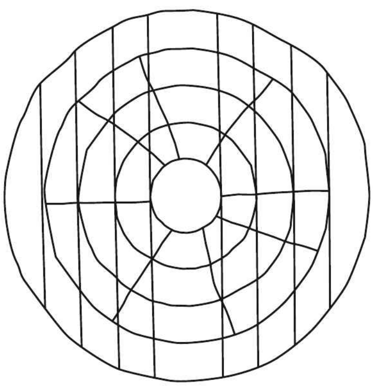
In timber, the outer (younger) layers are called *sapwood* and the inner layers *heartwood*. The sapwood is naturally more moist and softer than the heartwood. The heartwood provides the strength to the tree. A very small amount of cells which grow in the horizontal direction occur as groups or bundles of cell known as rays or *medullary rays*. They originate from the centre of the stem. Their function is to transfer food from the bark to the inside. In softwoods, these rays are not very well marked as there are only 2 or 3 cells in a bundle. In hardwoods there are many more cells in each ray and they are, thus, much more easily visible. They form an attractive pattern in the finished timber. At the centre of the trunk is the *pith or medulla*. It is the original stem and tends to decay after the tree reaches maturity. The layer between sapwood and inner bark is known as the *cambium layer*. It is the layer which is being converted to sapwood in a growing tree.

15.3 SEASONING AND CONVERSION OF TIMBER

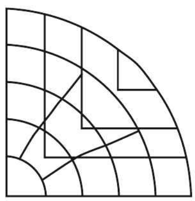
Freshly-felled wood contains a large amount of sap and moisture. *Seasoning* is the process of drying timber in a controlled condition to remove all the sap and to reduce moisture content without introducing any splits and distortion in the wood. The following are the procedures used for conversion and seasoning of timber.

15.3.1 Conversion to Timber

Immediately after felling of the trees, the branches are cut off and the trunk is cut into logs. The process of cutting and sawing logs into suitable sections of timber is known as *conversion*. In old days, this was done manually by saws but nowadays, it is carried out by band and circular saws run by machines. The types of sawing can be ordinary sawing, quarter sawing, tangential sawing or radial sawing as shown in Figure 15.3.

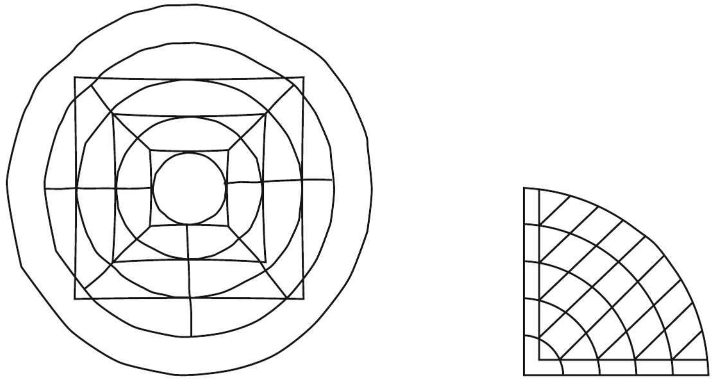


(a)



(b)

Figure 15.3 (*Contd.*)



(c) (d)

Figure 15.3 Sawing of timber. (a) Ordinary sawing (b) Quarter sawing (c) Tangential sawing (d) Radial sawing.

1. ***Ordinary sawing.*** In this type of sawing, the wood is simply sawed normal to its diameter. It is the quickest and the cheapest method of sawing. This is also the most economical method as wastage of useful timber is the minimum. This method is commonly used in India. However, as each plank has its outer portion of sapwood and the inner portion of heartwood, there will be differential shrinkage and warping. For this reason *quarter sawing* is used.
2. ***Quarter sawing.*** It produces fine timber when the wood has no distinct medullary rays. It produces a timber that has a tendency to get bend in the transverse direction.
3. ***Tangential sawing.*** It is also called plain sawing or flat-grained sawing. It produces planks which warp too much as the medullary rays which give strength to the longitudinal fibres are cut. These planks cannot be polished evenly.
4. ***Radial or rift sawing.*** This is the generally used method for hardwoods. The timber obtained by this method does not shrink much. It gives a decorative finish also due to interplay of grains. However, the wastage in this method is the maximum. After conversion, the timber has to be seasoned as described in next section.

15.3.2 Seasoning of Timber

We have already defined seasoning in Section 15.3 as the removal of sap and reduction of moisture in the wood. The following are the methods used for seasoning of timber.

1. ***Natural or air seasoning.*** Air seasoning of timber products after sawing is usually carried out by stacking sawn timber horizontally in layers in a covered shed. They are separated by wooden battens (called crossers or spacers). Air is allowed to freely circulate between the logs. The ends are generally painted with suitable material to prevent end cracking. This type of seasoning may take 2 to 6 months. This process can be hastened if before sawing, the logs themselves are first immersed in water for a fortnight (in a river with the thick end facing upstream) to remove the sap.

2. ***Artificial seasoning of timber.*** Seasoning of timber can be hastened if we use artificial seasoning. The following methods are used for this purpose before sawing them:
   (a) *Kiln drying.* The timber is kept inside an airtight chamber. First, fully saturated air at 35 to 38°C is circulated and then, the humidity is reduced slowly and the temperature increased till the timber is reduced to the degree of moisture required. Then, the kiln is slowly cooled.
   (b) *Boiling.* The pieces are immersed in water and the water is boiled for about 3 to 4 hours. This process removes the sap from the wood.
   (c) *Chemical seasoning.* Wood is immersed in salt water
   (d) *Electrical seasoning.* It is done by passing high frequency alternating current through timber.
   (e) *Water seasoning.* In this process, the pieces of timber cut to sizes are immersed in water preferably in running water of a stream with the thicker end of the original log kept upstream. In 2 to 4 weeks' time, the sap will be washed out. The timber is then taken out, stacked (so that air can freely circulate around the pieces) and air dried.

15.4 MARKET FORMS OF TIMBER

The following are the terms used for the commercial forms of solid timber available in the market. In addition, there are many industrially-processed wood products which are described in Chapter 16.

1. *Battens.* The timber pieces from 50 to 100 mm thick and 125 to 200 mm wide are battens.
2. *Planks.* The pieces with thickness less than 50 mm and width exceeding 50 mm are planks.
3. *Boards.* The pieces with thickness less than 50 mm and width 100 mm or more are boards.
4. *Baulks.* The timber pieces with cross section exceeding 50 mm × 50 mm are baulks.
5. *Deals.* These are softwood from 50 to 100 mm thick and width not exceeding 250 mm.
6. *Scantlings.* These are the pieces of small width and thickness (miscellaneous sizes), say 50 to 100 mm thick and 50 to 100 mm wide. (Thus we may call joists of 100 mm by 50 mm size as seantlings.)
7. *Quarterings.* These are the square pieces of timber of size 50 mm × 50 mm to 150 mm × 150 mm.

15.4.1 Loss in Conversion

The losses in conversion from logs to timber can be as much as the following, depending on the product.

Planks. From round logs 40%—From square logs 30%
Scantlings. From round logs 50%—From square logs 40%

Note: Door frames are usually made from wood scantlings of size 75 mm in thickness and 100 mm in width.

15.5 DEFECTS IN TIMBER

Civil engineers should be able to identify defects in timber and classify timber. Defects are unsightly and weaken the timber. Timber with defects is priced much cheaper than the good timber. The commonly referred defects which are important to look for while selecting timber for woodwork are the following:

1. ***Knots.*** These are the sections of the branches of the tree which will be present on the surface of wood in the form of hard dark pieces. Knots are source of weakness in timber when used to carry compression. They are called *nail knots* when diameter is less than 6 mm diameter, *small knot* when it is 6 to 20 mm *medium knots* when 20 to 40 mm and *large knots* when more than 40 mm. They can also be "*tight knots*" and "*loose knots*". Those knots which are securely joined to the adjacent wood are called tight knots. Timber with large and loose knots should be avoided. Knots are shown in Figure 15.3. All knots in timber used for buildings should be covered with two coats of shellac before the wood is painted.
2. ***Shakes.*** These are the cracks and splits in the felled log due to many causes. They can be cup shake, heart shake or circumferential shrinkage as shown in Figure 15.4.

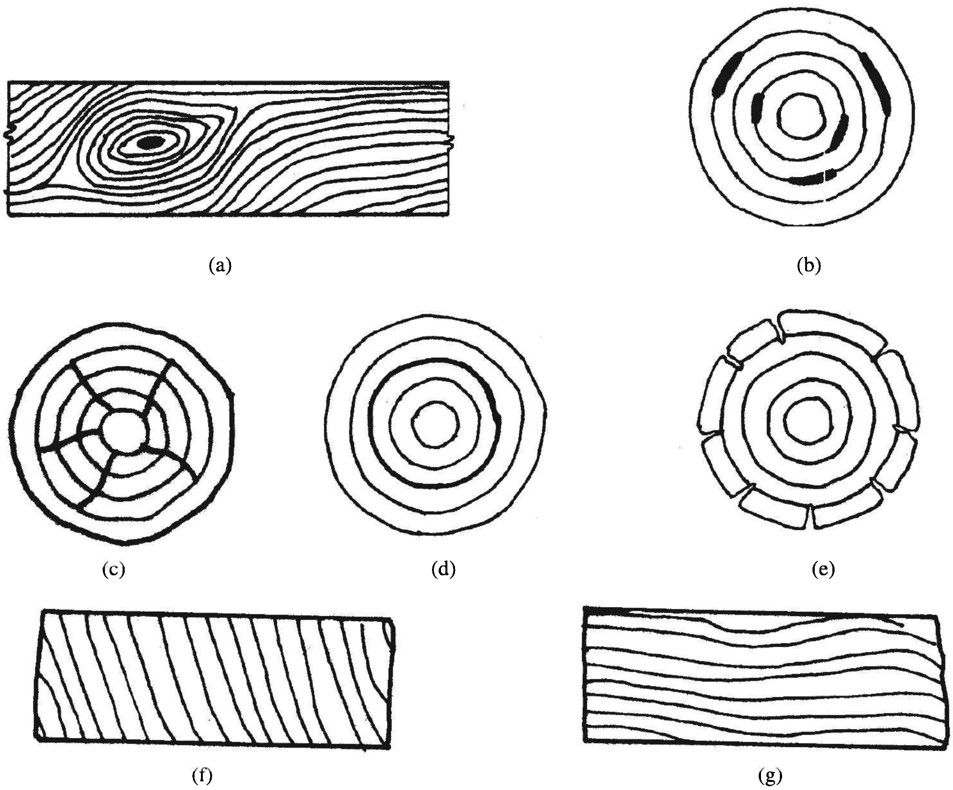


Figure 15.4 Defects in timber (a) Knot (b) Cup shake (c) Heart shake (d) Ring shake (e) Star shake (f) Twisted fibres (g) Upset.

3. ***Twisted grain or fibre.*** This defect is caused in the tree itself due to (action of) wind. The grains appear as shown in Figure 15.3.
4. ***Upset or rupture.*** This is caused due to an injury during the growth of the tree due to strong winds or bad felling of trees resulting in discontinuity of fibres.
5. ***Wane.*** It is the part of the original outside rounded surface of a tree that remains in the timber during conversion. It is important when the timber is used for important uses, but is not considered important when timber is used for works like shoring, piling, etc.
6. ***Presence of sapwood.*** Sapwood is less durable than heartwood and it should not be present in wood used in important places. Sapwood can be identified by the colour which will be much lighter than that of the heartwood. It also does not take as good polish as heartwood.
7. ***Sloping grains.*** In living trees, the cells do not always grow perfectly vertical or straight and parallel to the length of the trunk. The taper from bottom to the top causes sloping of grain in timber sawn parallel to the pitch. This defect is not as bad as the sloping grains obtained from the tendency of some type of trees for the cell to grow in a spiral pattern around the axis of the tree. Such sloping grains are considered as a defect.
8. ***Cracks, fissures, resin pockets.*** Cracks and fissures are fibre disruptions which appear in timber due to many causes. These disruptions affect the strength of timber. Resin pockets and fissures containing resins are defects which affect strength and suitability for decoration of the wood. A long narrow crack is called a streak.

15.6 TREATMENT OF TIMBER BEFORE USING IN WOODWORK

All woods other than teak should be as far as possible *treated with preservatives before they are used.* Teak wears well if protected from elements and also if air is allowed to circulate around it. Most of the other woods need protection even after they are used in construction. They should be maintained against deterioration. Thus, treatment of timber with preservatives should be carried out before it is used in timber work and regular maintenance like painting should be carried out after construction. (Timber can be made fairly fireresistant by soaking in ammonium phosphate, sodium tetra borate or sodium arsenate.)

15.6.1 Preservative Treatment of Timber

Preservative treatment of timber is carried out by one of the following methods. The method to be used will depend on the use of the wood in construction.

1. ***Charring.*** In this method, the surface is burnt and the burnt part acts as a protective coat.
2. ***Painting with tar or creosote.*** Tar or creosote, obtained from distillation of coal, has wood preservative oil in them. (Do not mistake bitumen for coal tar. Fence posts are preserved this way by coating with tar.
3. ***Treatment with preservatives.*** The following are some of the methods used:
   (a) *Brush and spray treatment.* Solvents or emulsions are used for this purpose. They are brushed or sprayed on the wood.

(b) *Immersion.* In this method the materials are immersed in the preservative solution for penetration.

(c) *Hot and cold open tank treatment.* This is the method used for treating fence posts with preservatives like creosote. The timber is placed in a steel tank immersed in a preservative and heated to about 85–90°C. Then, tank is allowed to cool slowly with timber immersed in the solution.

(d) *Pressure and vacuum treatment.* There are three methods in this procedure—the full cell process, the double vacuum method and the empty cell process. In the full cell process, the timber is placed in the closed vessel and is subjected to a low vacuum for about an hour. During this process, a preheated preservative is introduced until the vessel is full. Pressure up to 14 kg/cm^2 is applied, gradually increased, and kept constant for several hours, after which the pressure is reduced and the solution is drained out. The double vacuum method is the variation of the full cell process. In the empty cell process, the initial vacuum is omitted and various other features are incorporated.

One of the important preservative used in India for the treatment of timber is a material known as ASCU. It is a solution with compounds of arsenic (As_2O_5) Copper ($CuSO_4$) and Potassium chromate ($K_3Cr_2O_7$) in the proportion of 1:3:4 by weight. It is a product developed by Forest Research Institute of India for treatment of wood. It is available in powder form. This powder is made into a solution by dissolving it in water in the ratio 6 of powder to 100 of water in weight. This is a good preservative which should be impregnated in the wood by painting or by one of the methods described in the section. Vacuum treatment with this solution gives a very good durable product.

4. ***Treatment by diffusion.*** This is carried out on green timber (with moisture content over 50 per cent) just after conversion to green timber. Very soluble boron compounds are applied on the surface of the timber. The pieces are then stacked together and covered with impermeable cover to prevent evaporation. Over a period of one month or more, the boron diffuses into the wet timber and acts as a preservative.

15.6.2 Causes of Decay of Woodwork and Preservation of Woodwork

As already stated, woodwork in buildings like doors, windows, etc. should be maintained properly after they are put up in the building. Regions that depended on wood for their important buildings like Kerala and Sri Lanka have not left any monument for posterity whereas other regions in South India which used stones have left many monuments behind. This is due to the easy disintegration of wood with time. All woodworks require regular maintenance and treatment even if it is meant to last only for a short period. The principal causes of deterioration are the following:

(a) ***Fungal decay (dry rot and wet rot).*** The broad division of fungal attacks is dry rot (which occurs in slight moist conditions) and wet rot (which occurs in very damp conditions). Dry rot is more common than wet rot. The difference between these defects is the difference in the names of the fungus that attack the wood. Dry rot is not really dry. It is produced by a fungus that grows in moist conditions, moist basements and moist wood. It can remain dormant even when dry till wet situation returns. It occurs in wood that touches the soil, in bathroom door frames, joints of beams or where window frames are built against the sill. It can occur due to moist condition and *is a result of lack of ventilation*. It is more dangerous than wet rot as the spores spread through air to wood with as little as 25% moisture. Wet rot is produced by a different fungus that requires constant supply of moisture. Hence, it is called wet rot. It occurs in places of permanent leak or other places where water is constantly in present. The spores of this fungues do not spread through air.

Typical appearance of dry rot is white fungai threads of which bear spores or seeds of which can float in air. In wet rot the threads are black or dark brown in colour. The fruiting bodies are dark brown or olive green. They will not germinate in dry timber.

If fugal attack has taken place, then the remedy lies in drying out the material and removing the affected part, if the damage is extensive. We must also apply fungicide to prevent further reinfection. If the affected part is small, then it can be repaired by injection of epoxy resin. Sapwood and softwood are more amenable to attacks by fungus and beetles. The fungicides usually used are 20:1 dilution of water and sodium pentachlorophenate, sodium orthophenylphenate or mercuric chloride. Full safety measures should be taken while using them as they are harmful chemicals. Small holes can be drilled in the member part and it can be impregnated with the chemicals by injection.

(b) ***Attack by beetles and borers.*** These lay their eggs in holes and in surface cracks. The hatched larve tunnel through the timber all through their lives and live on the starch in the wood. Then they pupate and hatch to adult flies to repeat the same cycle. The most effective method against these insects is to treat the woodwork with insecticide and preservatives. One of the common treatment material used against beetles is turpentine mixed with a small quantity of orthodichlorobenzene. This vapour is said to be deadly to insects but not poisonous to human beings.

(c) ***Attack by termites.*** Attack by termites, especially in places where there is no human habitation in the building, is quite common in the tropics. Softwood is eaten more quickly than hardwood. The only remedy is to arrange for constant inspection and treatment with specific anti-termite chemicals. The commonly used chemicals against termites in wood are emulsions of Heptachlor (0.5%) or Chlordane (1%) or Chlorpyrifos (1%) *in kerosene oil*. New woodworks which will be in contact with masonry should always be painted with these insecticides and coaltar against termites before they are installed in position. If are attack happens on the put-up wood, then the chemical should be applied on it repeatedly. The above chemicals are available for sale in agrochemical shops.

(d) ***Maintenance by painting, etc. as a mean of preservation.*** In all cases, timberwork in a building should be preserved by oiling, painting, varnishing, etc. at regular intervals. Woodwork should have proper ventilation around it. It should not be placed in corrosive conditions as in lime or cement mortar or subjected to alternate wetting and drying.

15.7 CLASSIFICATION OF TIMBER

Specifications for timber used in building construction purposes is required to be *one of the following four* according to IS 4021 (1967):

(i) Hardwood like teak wood for permanent structures
(ii) Softwood like deodar for permanent structures
(iii) Hardwood like sal other than teak for permanent structures
(iv) Softwood other than deodar used only for temporary structures.

Wood is are classified into various classes by visual grading. For visual grading, all the four faces over the whole length of a piece is inspected for estimating the amount of defects in the timber. Each section should comply with the limits set out for the classification.

15.7.1 Classification of Teak

Teak is classified into three grades namely *superior, first and second classes* depending on the defects. On the other hand, the other three types of wood (ii) to (iv) above are divided only into two grades or classes, namely *first* and *second classes.* The above classification is made on the basis of the permissible defects for various classes of timber specified in IS 4021-1967 and is given in Table 15.2.

Table 15.2 Permissible Defects for Classification of Teak

S.No.	Defects	Superior grade (class)	First grade (class)	Second grade (class)
1.	Cross grain (not steeper than)	1/20	1/15	1/12 (One twisted grain per member allowed)
2.	Knots	$\ngtr$ 12 mm	$\ngtr$ 25 mm	$\ngtr$ 40 mm
	(a) Percentage area of piece	$\ngtr$ 0.5%	$\ngtr$ 1%	$\ngtr$ 1.5%
	(b) Maximum size	$\ngtr$ 10 mm	$\ngtr$ 25 mm	$\ngtr$ 40 mm
3.	Pith, pockets or streaks	None	None	Permissible, if filled with putty, etc.
4.	Sapwood	None	None	Traces allowed
5.	Pin holes	None	None	Filled up ones permitted
6.	Worm holes	None	None	One of $\ngtr$ 9 mm per member and treated

15.7.2 Classification of Deodar

For classifying of woods (other than teak) like deodar which is a conifer, we adopt the two classes—first class and second class.

First class. No individual "hard and sound knot" shall be more than 25 mm in diameter and the aggregate area of all the live knots shall not exceed 1 per cent of the area of the piece. Wood should be free of sapwood.

Second class. No individual "hard and sound knot" should exceed 40 mm in diameter and the total area of all of the knots in the piece should not exceed 1.5 per cent of the area of the piece. Wood should generally be also free from sapwood but traces of sapwood are allowed.

15.7.3 Classification of Sal

Another hard wood that is classified as good is salwood. It grows in sub-Himalayan regions and in Madhya Pradesh and is heavier than teak. It has to meet the requirements of first class deodar for use as beams, rafters, wood block for floors, etc.

15.7.4 Secondary Species

There are many other timber classed as *secondary species*. Mango, Benteak, etc. come in this class. The guide for selection of wood is that, the local wood traditionally used in that area of the country for each part of the building should always be selected for use for such parts.

15.7.5 Stress Grading of Timber

In U.K. and other western countries, stress grading of timber is used. Such type of grading, employing machines, is used on some woods on the assumption that the modulus of elasticity and modulus of rupture found by test on a short span can be used for such grading. This method has not yet been accepted in India.

Note: Teak wood can be used for all parts of a building. Among other types of wood called secondary species, some types are used for specific purposes. The secondary species used for door frames, door shutters, etc. in a building in any part of India should correspond to the species usually used for such works in that region. The wood popularly used in South India differs from that used in North India as trees grown in these regions differ from one another.

15.8 PERMISSIBLE MOISTURE

The permissible moisture in wood depends on the relative humidity that occurs in the place where it is used. IS 287-1993 "*Recommendations for Maximum Moisture Content of Timber*" gives the following values for beams, rafters and posts not less than 50 mm in thickness.

Zone I	Dry zone (R.H. $<40\%$)	:	12%
Zone II	Moderate dry zone (R.H. 40–50%)	:	14% (average value)
Zone III	Moist zone (R.H. 50–67%)	:	17%
Zone IV	Moist zone (R.H. $>67\%$)	:	20%

For door and window shutters as well as furniture and thinner sections, the moisture content is to be taken less than the above values. Protection from entry of moisture after installation of woodwork is obtained by painting of woodwork that are exposed to sun and rain. For protecting timber like teak "wood oiling" will serve the purpose.

15.9 SELECTION OF WOOD FOR BUILDINGS

Different qualities are prescribed for different uses of wood. The wood suitable for doors and windows is different from that used for beams and columns. In all cases, teak is considered as an ideal wood for use in buildings. *For columns, beams, door frames, etc.* we look for the wood which is locally available but with respect to the following qualities:

(a) Class to which the wood belongs. We use teak of superior class or other types of wood of class I for important works
(b) Closeness of grains
(c) Hardness and durability
(d) Pleasing colour
(e) Easiness of working
(f) The way it can take polish

15.10 TESTING OF WOOD

Wood for building construction is not generally tested in the laboratory before using in construction. It is classified more only by its species and by visual examination for defects. The properties are assigned accordingly. However, if required, some of the followings tests are prescribed for important works.

1. Determination of moisture content
2. Tensile strength parallel to grains
3. Tensile strength perpendicular to grains
4. Charpy test for brittleness

We will review only the moisture test which is the only test that is generally required in building construction by government departments. The allowable moisture is usually taken as given in Section 15.8. Even though the mechanical properties of wood are not affected by moisture to any significant extent, presence of high moisture in timber produces shrinkage in woodwork. Moist wood is also more prone to attack by organisms. Shrinkage produces cracking, warping and lack of fit of woodwork in doors and windows. Even blistering of paints occurs if the wood has too much moisture before it is painted.

15.10.1 Test for Moisture

The two methods used for testing moisture content are the following. (A sampling rate of one sample for every 10 cubic metre or part thereof is usually specified.)

1. By taking samples and determining moisture content by heating in an oven to 100–105°C.
2. *By electrical moisture metres.* These metres are limited in range between 8 to 25 per cent moisture content only. This method is not as precise as the oven drying method.

For the oven drying method, a test section is used for the test. In case cutting of test section from the piece is not permissible, the moisture content, can be determined by collecting the boring material obtained by means of an auger, the hole being bored only to one half the depth of the piece and sealed later.

SUMMARY

Timber is becoming more and more scarce and commercial timber products as well as substitutes like plastics are being used more and more for building construction. However, civil engineers should be able to identify the types of local wood that can be used for the various parts of a building. It may sound rather strange that at present most of the timber sold in local markets are those imported from countries like Malaysia, Africa, South America. The performance of these species in local conditions should be studied before they are recommended for local use.

REVIEW QUESTIONS

1. (a) Sketch the diagram of a growing tree showing its different parts.
(b) Sketch the cross section of the trunk of a tree and indicate the different parts of a log of wood.

2. Distinguish between the following:
(a) Endogenous and exogenous trees
(b) Hardwood and softwood
(c) Sapwood and heartwood
(d) Knots and shakes

3. Give a brief account of the defects that you look for in timber. How do you classify teak wood and other types of wood?

4. Describe the four methods of sawing used to convert wood into timber products, giving your comments on each of the products.

5. What are seasoning and preservation of timber? Describe the commanly used methods of (a) seasoning (b) preservation of timber.

6. What are the causes of deterioration of woodwork in a building? How can you rectify them and also prevent them?

7. How is teak graded compared to other types of wood?

8. Name the types of wood you will use for each of the main parts of a sloped roof building in your locality?

9. Write short notes on:
(a) ASCU treatment
(b) Methods for determination of moisture content in timber
(c) Stress grading of timber
(d) Fungal decay of timber
(e) Market forms of timber

10. Describe dry rot and wet rot. What are the differences between them and how will you identify them? How can they be prevented? How do you treat them if they have already affected the wood?

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[1] IS 287–1993: *Permissible Moisture Content for Timber used for Different Purposes—Recommendations.*

[2] IS 401–2001: *Preservation of Timber—Code of Practice.*

[3] IS 1141–1993: *Seasoning of Timber—Code of Practice.*

[4] IS 7315–1974: *Guidelines for Design, Installation and Testing of Timber-seasoning Kilns.*

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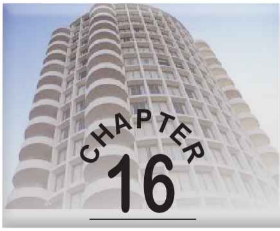


CHAPTER 16 Industrial Timber Products

16.1 INTRODUCTION

Nowadays, solid wood of good variety is in short supply, particularly when wide and thin pieces like door shutters and table tops are required. Natural wood can be made into many other industrial products by industrial processes for building construction and also for making furniture. These products are also known as *composite boards*. The common industrial products of timber meant for these purposes are the following.

1. Plywood
2. Particle board or chipboard
3. Hardboard
4. Fibreboard
5. Blockboard
6. Flushdoor shutters

There are also a large number of synthetic laminates that can be used with wood for decorative purposes. A brief account of the above products is given in this chapter. Boards with ornamental finishes on the surface are called *ornamental grade* while others are called *commercial grade*.

Note: Construction using two or more different materials is called composite. We thus have composite masonry where we use brick and stone, composite beams with steel and wood. *Laminates* are those materials built in layers.

16.2 VENEERS AND VENEER PLYWOOD (IS 303–1989)

Veneer plywood is commonly referred simply as plywood. For making plywood, round logs are first cut into logs of 1.5 to 2.5 m lengths. They are then steamed and veneers are cut from these pieces with a wide sharp knife extending the full length of the log. These veneers are glued together to form plywood. Generally, three or more veneers are glued together with the grains crossing each other.

This cross graining increases the strength of plywood. There are many types of classification of plywood. In the main classification, there are three grades—ordinary grade, exterior grade and marine grade.

Plywood of *ordinary grade* is ordinary plywood used for packing tea-chests, etc. ***Exterior grade*** plywood is made of durable wood bonded fully with waterproof glue. Of better quality than the exterior grade is the special ***marine grade*** plywood in which the core plys as well as the exterior veneers are of good quality and close-fitting wood.

Plywood can also be given an extra face of choice veneer of teak or rosewood either at the site of work by the craftsman or the manufacturer so that it can match surrounding types of solid wood. Laminated plastics are also very popular for this veneering for furniture making. Better quality plywood is also called *commercial plywood*. According to CPWD specifications *plywood for general purposes are of three grades*:

1. BWR (Boiling waterproof)
2. WWR (Warm waterproof)
3. CWR (Cold waterproof)

The above property depends on the type of synthetic resins used as adhesives (See Section 26.2.1). For panel door shutters, etc. BWR grade plywood is recommended. There are also the following rules regarding thickness of plywood:

1. For 3 play boards (up to 5 mm thick), the combined thickness of the face veneers should not exceed twice the thickness of the centre ply.
2. In multiply boards, the thickness of any veneer should not be more than thrice the thickness of any other ply.
3. The sum of the thicknesses of the wood with veneers in one direction shall be approximately equal to the sum of the thickness of veneers at right angles to them and in any case, it should not be greater than 1.5 times this sum except for the 3 ply given above.

The thickness of plywood boards are specified in mm. The following thicknesses are the standard:

3 ply (4 mm)
7 ply (12 mm, 15 mm, 16 mm)
9 ply (12 mm, 15 mm, 16 mm, 19 mm)
11 ply (19 mm, 22 mm, 25 mm)

16.3 PARTICLE BOARD OR CHIPBOARD

These boards are made with particles of wood (or other materials like rice husk or bagasse obtained from sugarcanes after crushing) embedded in synthetic resins and subjected to heat with pressure. They are manufactured by extrusion pressing or by pressing in parallel plates. The former process orientates the wood particles in the direction at right angles to the plane of the board and the latter orientates the particles parallel to the plane of the board. The particle board used for panelling of the door shutters is usually FPTH boards (see below) bonded with BWR (Boiling waterproof) type synthetic resin adhesive. The shrinkage in thickness and length of particle board should not exceed 5 per cent. The following are the designations:

(i) Flat pressed *single layer* particle board — FP SL
(ii) Flat pressed *three layer* board — FP TH

(iii) Extrusion pressed *solid board* XP SO
(iv) Extrusion pressed *tubular core board* XP TU

Particle board is heavier than comparable solid wood or plywood but it provides broad and stable panels of reasonable strength. They can be sawn like wood. For furniture making, these boards are available with plastic veneers on the outside. They are available in thickness of 5 to 50 mm and different widths and lengths depending on the manufacturer. Particle boards are more commonly used for furniture making than for building construction.

16.4 HARDBOARD (IS 1658–1977)

Hardboard is made from wood that is pulped and compressed to make sheets usually 3 mm thick. The face surface is smooth and hard and the opposite side is rough with pattern or cross lines. It is classified in CPWD specifications into three following types:

(i) Medium hardboard (density 480–800 kg/m^3) available in 6 mm, 8 mm, 10 mm and 12 mm nominal thickness.
(ii) Normal hardboard (density 800–1200 kg/m^3)
(iii) Tempered hardboard. (Hardboard specially treated for strength, density and water resistance).

The normal and tempered hardboards are available in 3 mm, 4 mm, 5 mm, 6 mm and 9 mm, and 12 mm thicknesses. The width of hardboards is usually 1.2 m and lengths 1.2 m, 1.8 m, 2.4 m, 3.0 m, 3.6 m, 4.8 m and 5.5 m. The tolerance allowed is ±3 mm. Only tempered quality as mentioned above should be used for door shutters, etc.

16.5 FIBREBOARD (IS 12406–1988)

The technology used to make fibreboard is a combination of those used for making particle board and hardboard. For making fibreboards, wood chips are steamed *to separate the fibres from each other.* These fibres are blended with resin and wax and turned into sheets by passing through a pressing machine under controlled heat, and pressure. These boards are available in thickness of 25 mm to 32 mm and as sheets 2.44 m × 1.22 m. Medium density fibreboards are called MDF particle boards. They are suited for mass production of furniture, cabinets, etc. and flush doors as in Figure 16.2 in Section 16.7.

16.6 BLOCKBOARD (IS 1959–1990) AND LAMINBOARD

(*Blockboard* is also known as *battenboard* or *solid-core plywood*). Blockboards are thicker than most of the plywoods and have a core made of strips of wood each not exceeding 25 mm in width, laid separately or glued or otherwise jointed to form a slab with the direction of the grains of the core blocks running at right angles to that of the adjacent block. The slab is then glued between two or more outer veneers on either side as shown in Figure 16.1(a). Thicknesses are from about 19 mm upwards. They are suitable for items like table tops, door panel and similar pieces of large areas.

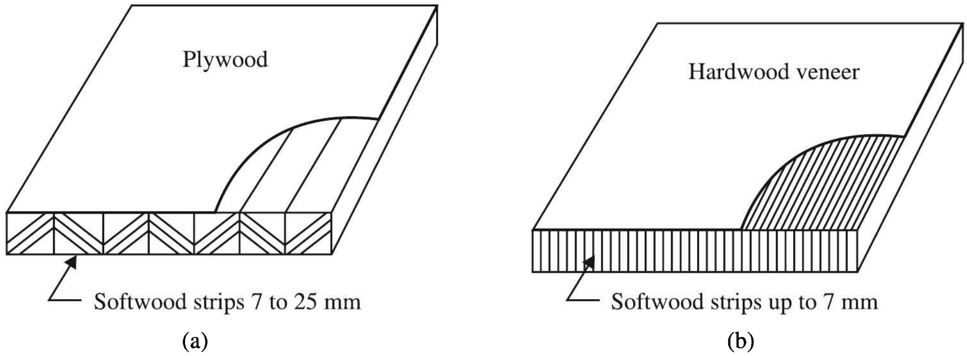


Figure 16.1 (a) Blockboards (battenboards) and (b) Laminboards.

When blockboards are made for panelling of door shutters, the plywood should be of grade I, exterior grade bonded with BWR synthetic resin adhesive. They are classified according to CPWD specification as the following types:

Type 1: Decorative type (X DEC) with ornamental veneers on one or both sides

Type 2: Commercial type (X COM) with faces of commercial timber

16.6.1 Laminboards

When the core strips consist of a core made up of large pieces of 80 mm width, it is called *blackboard* or *battenboards*. On the other hand, if the core consists of strips each not exceeding 7 mm in thickness, it is called *laminboards* [see Figure 16.1(b)].

16.7 WOODEN FLUSHDOOR SHUTTERS

With the development of plywood and blockboard industry, factory-made flush doors have become very popular for interior door work. These doors are available in thickness of 25 mm, 30 mm or 35 mm. They are available in the types as shown in Figure 16.2:

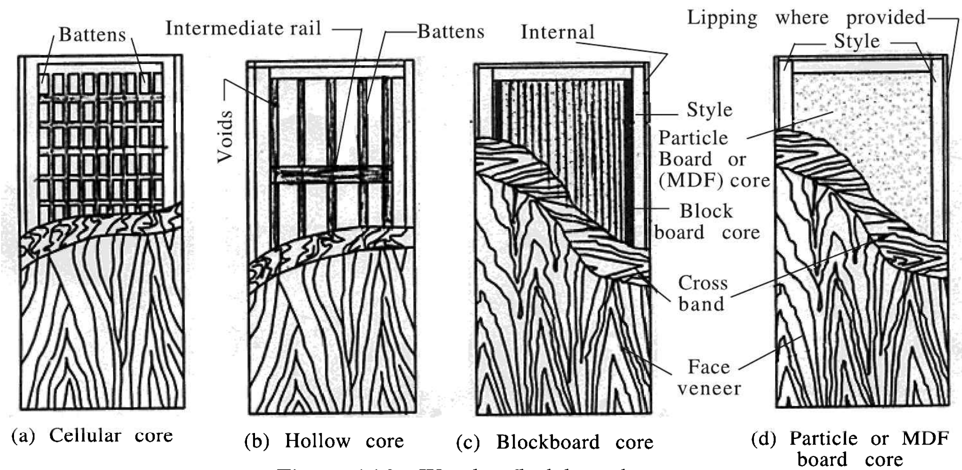


Figure 16.2 Wooden flushdoor shutters

1. Cellular core type
2. Hollow core type
3. Solid core type (made of blockboard or particle board)

CPWD specification 77 gives the following three tests to test the quality of flush floors:

1. ***End immersion test.*** In this test, the end of door shulter is immersed in water at room temperature (27±2°C) for a height of 30 cm for 24 hours and then allowed to dry for 24 hours. This is repeated 8 times. There should be no delamination at the end of the test.
2. ***Knife test.*** In this test, a thin knife is inserted below the outer veneer and raised upwards. A good specimen should give considerable resistance for insertion and raising of the veneer.
3. ***Glue adhesion test.*** For this test, a 150 mm × 150 mm piece is cut and immersed in boiling water for 4 hours and cooled for 24 hours. At the end of the test, there should be no major delamination.

16.8 GLULAM

Glued and laminated wood is called "Glulam" (GLU-LAM). It is not made of veneers but with solid wood. Solid wood is glued to large sections. Components made from this process are especially suitable for support of long span roofs for sports stadiums, indoor swimming pools, sheds for chemical factories, etc., where other materials like steel cannot last long. They can be used as beams of many shapes including curved members. The timber sections are first dried in a kiln. They are then machined to form interlocking V cuts across the width and the end sections of each piece. Suitable glues are then applied and the pieces are forced together under longitudinal pressure while the glue cures. However, for their fabrication, good shop facilities for woodworking and glueing are necessary and hence, they are not very popular in India.

16.9 LAMINATES

Laminates are the products made by bonding together of two or more layers of materials. Products such as plywood, glass laminates, composite glass laminates all come under this class. Special laminates from plastics are also available in the market. These can be glued to wood to make the surface aesthetic as well as heat-resistant. As these laminates come in large width, furniture like large table tops can be made of joined wood pieces and covered with these laminates to give an appearance of a one-piece furniture.

16.9.1 Decorative Laminates (IS 2046–1995)

High pressure decorative laminate (HPL) on plywood sheets are used for surfacing of large areas like that for tables, cabinets, etc. They are available in thicknesses of 0.8 mm, 1.0 mm and 1.5 mm, their backside being suitable for adhesive bonding to surfaces made of less broader planks. Standard size of a HPL sheet is 1.22 m × 2.44 m.

As given in Chapter 24 these decorative laminates are manufactured by assembly of impregnated papers. Kraft paper impregnated with Phenol Formaldehyde (PF), forms the core of the laminate. Below the kraft paper we have a barrier paper, and also a base or design paper. An overlay of tissue paper impregnated with Melamine Formaldehyde (MF) resin is provided over the kraft paper. The a melamine layer is given as a protection and also to enhance abrasion resistance. They are pressed in a hot press between stainless steel plates to ensure good finish. These sheets can be bonded to wood with suitable glue and the whole area of the sheet is kept under a pressure (by pressing it down with weight) so that the two areas come entirely in contact with each other.

16.10 MERITS OF PROCESSED TIMBER

The following are the merits of processed timber:

1. ***Use of unusable wood.*** The raw materials used for processed timber are those parts of a tree (like branches) of good wood and also the fast growing trees both of which cannot otherwise be used in construction.
2. ***Lowering of cost.*** By converting expensive wood into thin veneers, large surface area of these can be covered with reduced cost.
3. ***Dimensional stability.*** Processed timber is *dimensionally stable*. Plywood and blockwood do not absorb moisture from air in wet weather. However, particle board tends to absorb moisture.
4. ***Durability.*** Depending on the gluing materials, plywood and blockboard are very *durable* in wet locations. The durability depends on the grade of adhesive used.
5. ***Workability.*** These materials are workable like wood.
6. ***Holding power of fasteners.*** Plywood and blockboards can be fastened like other wood. However, particle boards and MDF (medium density fibreboards) usually require special fasteners:

The main disadvantage of these commercial products is that unless they are made of reliable materials (like good water-resistant glue, etc.) and made by reliable manufacturer, they tend to become unusable on getting wet or with time. Their use in situations like door shutters for bathroom doors and external doors is usually restricted or if used in these places, it should be carried out with great care.

SUMMARY

Industrial timber products are used extensively in building construction and for furniture manufacturing. We must be able to distinguish between the various products and then choose the most suitable material for our use.

REVIEW QUESTIONS

1. What is plywood and how is it classified in CPWD specifications

2. Write short notes on:

(a) Glulam

(b) Hardboard
(c) Chipboard
(d) Blockboard
(e) Particle board
(f) Laminates

3. Enumerate the different types of processed timber products that are available in the market. What are their merits and demerits?

4. What are the different standard types of flushdoor shutters that are used for buildings in India?

5. What are composite boards? Give examples of five composite boards and indicate how they are manufactured.

6. Describe the tests specified by CPWD to test the quality of wooden flush doors.

REFERENCES

[1] IS 303–1989: *Plywood for General Purposes—Specification.*

[2] IS 710–1976: *Marine Plywood—Specification.*

[3] IS 3087–1985: *Wood Particle Board (Medium Density) for General Purposes—Specification.*

[4] IS 3129–1985: *Low density Particle-board—Specification.*

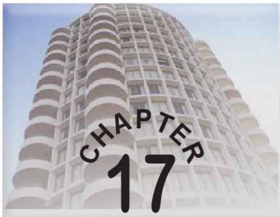
[5] IS 1658–1977: *Fibre Hardboard—Specification.*

[6] IS 1659–2004: *Blockboards—Specification.*

[7] IS 1328–1996: *Veneered Decorative Plywood—Specification.*

[8] IS 4990–1993: *Plywood for Concrete Shuttering Works—Specification.*

[9] IS 12406–1988: *Medium Density Fibre-board—Specification.*



CHAPTER 17

Glass for Buildings

17.1 INTRODUCTION

The glass industry makes a variety of glass products. Sodalime glass is the cheapest variety of glass and is used for bottles, windowpanes, etc. Pyrex glass (or borosilicate glass) is used for heating vessels. Bottle glass is used for medicine bottles. In this chapter, we will confine ourselves to glass that is commonly used in building construction.

17.2 MANUFACTURE AND CLASSIFICATION

Glass is made by heating soda (NaOH or KOH), lime ($CaCO_3$) and sand (SO_2) with some broken glass to about 1710°C, at which they melt and fuse. The molten glass is either drawn continuously as clear *sheet glass* or rolled out and polished on both sides as *plate glass or produced after floating on tin as float glass*. The evaluation of the different methods of manufacturing of glass is a fascinating story and is briefly described below.

In very early days, glass was made into different objects by the blowing process by glass blowing labour. To satisfy the demand for flat glass for buildings, the molten glass was blown first into a cylinder. The cylinder was then split open, reheated and flattened to make flat glass. By this process, only small size glasses could be made. This led to the gradual evolution of the methods of (a) drawing for making *sheet glass* (b) rolling for making *plate glass* and (c) floating for making *float glass*. Those interested in building construction should be able to distinguish between these three types.

***Drawing to make sheet glass* [Fig. 17.1(a)].** The basic procedure used for manufacturing sheet glass is drawing. First, glass is produced in the molten state. A bait (steel rod) is inserted into this molten glass and as it has a high viscosity, it adheres to the rod. With this bait, the glass can be *drawn vertically upwards* (between jets of flame) by rollers. The glass becomes fire polished and becomes transparent. Once the drawing process is started, pulling rollers keep it going upwards, enabling a continuous sheet being drawn from the molten glass. The glass surface undergoes rolling and annealling and allowed to be cooled gradually. The glass produced by this drawing process is called *sheet glass*.

***Rolling to make plate glass* [Fig. 17.1(b)].** Plate glass was basically made by *casting glass horizontally and polishing* it. However, in about 1922, the continuous rolling methods to produce plate glass were introduced. In this process, the molten glass is flowed horizontally through an opening into the water-cooled "forming rolls". They roll the molten glass as a continuous strip to the necessary thickness and up to 3 m in width. They can be ground and polished to be cut into different sizes of plate glass.

Floating to make float glass **[Fig. 17.1(c)].** This is the most modern method of making glass for various uses. The float process was invented by the firm Pilkingten Bros. Ltd. of England to combine the benefits of the methods of manufacturing of sheet glass and plate glass. The fire polishing and low cost of the drawing process to make sheet glass is combined with the flatness and low distortion to make plate glass. It uses the principle that when a lighter fluid floats over a heavier fluid, the surface of the lighter fluid becomes flat and parallel. The float process is shown in Figure 17.1. The molten glass leaving the tank is floated on a truly horizontal bed of molten metal composed of tin. When the liquid glass floats horizontally across the float bath, it forms into a thin layer with parallel surfaces. In this process, plastic glass also receives an intense fire polished surface. It is slowly cooled while passing between the rollers in its plastic state. It is then annealled to relieve built-in stresses and made into the required sizes.

The manufacturing of sheet and plate glass is now being replaced by float glass because of its cheapness and good quality. Float glasses are, at present, the commonly used variety of glass used in modern buildings.

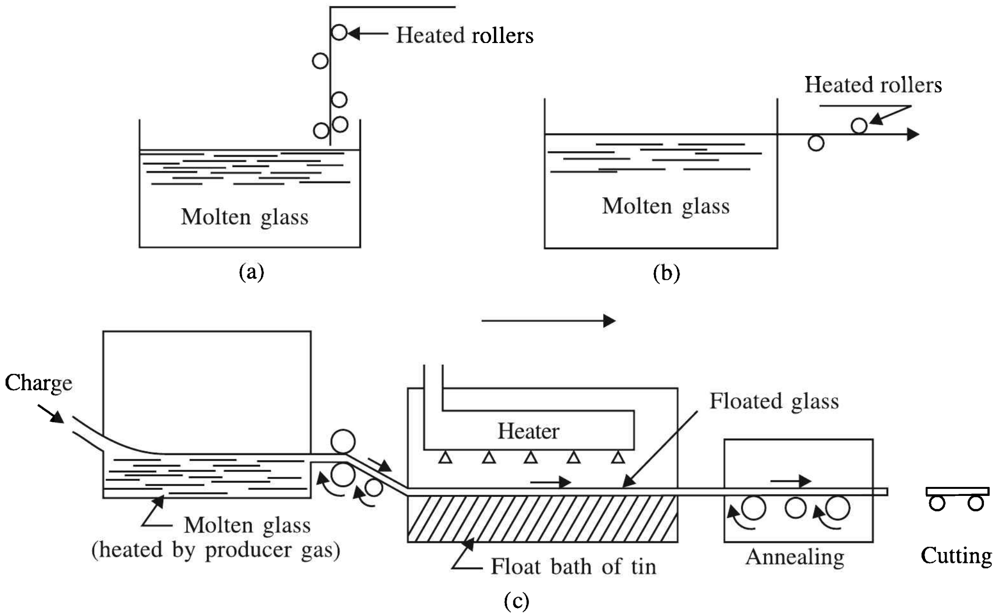


Figure 17.1 Manufacture of glass (a) Sheet glass (b) Plate glass (c) Float glass.

In the final analysis, the selection of the type of glass to be used will depend on its use, the cost and the class of building under consideration.

17.3 TREATMENT OF GLASS

There are many treatments that can be given to glass to improve its properties and appearance. For example, by heat treatment, we can make *tempered glass*. Fully-tempered glass is 3 to 5 times stronger than ordinary annealled glass of same thickness. For use in high rise buildings, it can be given a reflective coating so that images of clouds and nearby trees are reflected from them. Such glass is also called "*environmental glass*" as it reflects the environment. *Tinted glass* which keeps out the glare can be made by addition of specific ingredients to the basic glass-making materials. *Silvering* is carried out by an automatic process of spraying silver nitrate and tin-chloride. For permanent protection of the silvering, an electroplated layer of copper or a coat of special paint is applied on the silvering. Float glass is used for large sized mirrors. Only cheap small sized objects are made from sheet and plate glasses. Nowadays, most of the glass is produced by floating.

17.4 USES OF GLASS

Glass is used in various parts of buildings as fixed or openable glazing for architectural features and also to admit natural lighting. The types of glass available for glazing of buildings are sheet glass, plate glass and float glass. Selection depends on required size and cost of glass. Their use can be detailed as follows:

(a) ***Sheet glass.*** This is used in *small panels* of doors and windows for building purposes. They should be clear, free from blisters, scratches, waves, bubbles, etc. It is available in thicknesses of 2 mm, 2.5 mm, 3 mm, 4 mm, 5.0 mm, 5.5 mm and 6.5 mm. Usually, glass is specified in weight per unit square foot or square metre. Thus, 21 oz. glass means the glass which weighs 21 oz. per square foot in f.p.s. system (it will be 6.3 kg per sq. metre). There are many types of sheet glass as given below:

1. AA Quality or Special Quality (SSQ) for special use as mirrors
2. A Quality or Selected Quality (SQ) for special use as safety glass
3. B Quality or Ordinary Quality (OQ) for glazing in buildings
4. C Quality or Greenhouse Quality (GQ) for making frosted glass, etc.

Of these, OQ glass is mostly used in buildings. The usual specification for buildings is to use 21 oz. sheet glass for panels up to 24 inches, 28 oz. for panels of 24 to 30 inches and 32 oz. for panels of 30 to 36 inches.

(b) ***Plate glass.*** This type of glass is stronger and more transparent with much less waviness than sheet glass. It is to be used for large size panels such as shop windows, manufacture of mirrors, etc. It is manufactured in thicknesses of 3 to 32 mm. In building construction for panels over 900 mm (36 inches) dimension, 6.5 mm (quarter inch) plate glass is recommended. It is available in three varieties, rough cast, rolled (patterned) and polished. Unless otherwise specified, the term plate glass denotes the polished variety.

(c) ***Float glass.*** As already seen, this type of glass is prepared by passing the molten glass from the furnace through a molten tin bath (float bath). Since the free standing surface of the tin bath is very smooth, the float glass is of uniform thickness with excellent optical clarity and aesthetic appearance. It is further annealled to relieve all the stresses. Most of the modern large sized shop windows and facade of tall buildings are made of this type of glass.

(d) ***Wired glass.*** It is the type of glass in which wire setting is embedded in plate glass during rolling. This type of glass resists fire much better. Often, this type of glass is used for skylights.

(e) ***Translucent glass (Obscured glass or frosted glass).*** In this glass, a pattern or texture is imprinted on one or both faces so that the images cannot be seen through. This type of glass is used in doors and windows for bedrooms, lavatories, bathrooms, etc. Usually, only one face *is textured (frosted)* and the other side is flat. *The textured side should face the inside of the room (to be made obscure) and the plane glass side should face the other side*. This resists dust collection and easy drainage of rainwater. In any case, the frosted side is kept away from the putty side, if the glass is fixed by putty.

(f) ***Glass blocks.*** They are glass units, transparent or translucent, produced by a pressing process in which firstly two hollow dishes are formed which are then fused together to form a hollow, hermetically-scaled block. They have a high degree of thermal insulation and noise reduction. They can be used on walls and roofs.

(g) ***Laminated safety glass (Safety glass).*** This type of glass produced by bonding together two or more pieces of glass with plastic interlayers. If broken, the glass adheres to the inner layer, thus reducing the risk of injury to people. Such type of glass is used in automobiles for windows and windshields.

(h) ***Glass as structural glazing.*** A large number of multistoreyed buildings are faced with glass. Special glasses are available for this purpose. They are usually coloured or mirrored in order to shade direct sunlight and are heat-resistant.

(i) ***Plastic sheets for glazing.*** A great variety of plastic sheets, like polycarbide sheets which look like glass are also available for glazing. They can be very strong against impact so they are ideal for shop windows. They are also commonly used in roofs.

(j) ***Bulletproof glass.*** This type of glass is prepared by special techniques and will be up to 200 mm in thickness. Nowadays, plastics like polycarbide is more often used for this purpose.

(k) ***Tinted glass.*** Tinted glass, as already stated, is glass with colour. It comes in three shades bronze, dark grey and autogreen—thickness ranging from 2 to 12 mm. It absorbs 30 to 40 per cent of solar radiation (depending on the tint and thickness) compared to only 15 per cent absorbed by clear float glass.

17.5 TESTING FOR QUALITY

IS 1761–1960 gives the specifications for transparent glass used for glazing. The important attributes of glass for using in glazing are the following:

(i) ***Quality.*** Glass should be clean, free from blisters, scratches, bubbles, etc. that impair the visibility.

(ii) ***Waviness.*** The sheet glass should not show any distortion of light when tested according the standard test specified in IS 1761 for waviness.

(iii) ***Tolerance of size.*** The following tolerances are allowed in the length and width of sheet glass.

±1.5 mm for glass of thickness 2.5 mm and below

± 2 mm for glass of thickness 3.0 mm and above

(iv) The weights of sheet glass for various thicknesses are given in Table 17.1. The glass used for panels should not be less than 7.5 kg/m^2.

Table 17.1 Weights of Sheet Glass

Normal thickness (mm)	Range of thickness (mm)	Weight (kg/m^2)
3.0	2.8 to 3.2	7.5
4.0	3.8 to 4.2	10.0
4.8	4.6 to 5.1	11.9
5.5	5.2 to 5.8	13.5
6.3	6.0 to 6.6	15.5

17.6 CHARACTERISTICS AND PERFORMANCE OF GLASS

In construction of ordinary houses, glass is used primarily in windows and sometimes in doors. The main aim of using glass is to receive as much daylight into the building as needed. The glare associated with windows can be reduced by using slightly tinted glass. Glare can be caused by direct sunlight (direct glare) or from the bright sky (sky glare) or reflected from close surfaces (reflected glare). Glass should be used in buildings with due consideration to the following three items:

17.6.1 Solar Control

Clear glass transmits incident *short wave* solar radiation. This is absorbed by the surfaces like walls, ceiling furnishes inside the building which heats them up. This, in turn emits *long wave* radiation which does not pass out through glass. Thus, the radiation admitted by the glass gets trapped in the rooms resulting in rise in temperature. This is called "green house effect". In air-conditioned rooms, this affects the efficiency of the system very badly. Such solar gain can be reduced by external shading devices such as screens, blinds, canopies, etc. or internal shading. External shading is more effective than internal shading. The position of the windows with respect to the sun in summer is also important. These factors are important in air conditioning of buildings.

Another method to reduce this heat is by using solar control glasses which are of two types, the solar reflecting and solar absorbing. In general, the reflecting type is more efficient than the absorbing ones. The performance of the latter can be improved by double glazing using clear glass as the inside leaf.

17.6.2 Wind Loading

In very tall buildings, the glass used should withstand the wind load and the details of fixing should also be properly designed. While using glass as structural glazing for multistoreyed buildings, special devices are used to fix the glass sheets to their supports.

17.6.3 Sound Transmission

Double glazing of windows greatly reduces sound transmission of sound through windows. Sound insulation from outside depends on the size of windows, thickness of glass and air space between glass in double glazing. The air space between the glass should be properly adjusted in places where sound is to be isolated.

17.7 GLASS WOOL (GLASS FIBRE)

When glass melted at 1300–1400°C and is blown by a steam jet, it splashes out to form small globules which can be drawn into fibres of not more than 10 micron diameter. The fibres are chemically inert and have low coefficient of heat conductivity. It has many uses. This is used for filters in air conditioners, fine aggregates for finishing plasters to reduce cracking, etc. Nowadays, it is also an important material to be used with plastics to produce glass-reinforced plastics (GRP), which is being used for many purposes such as waterproofing of roofs, manufacture of water tanks, etc. We should remember that if cement and glass come together, then the alkali of the cement has an effect on the glass.

SUMMARY

Glass is used extensively in building construction. There are many types of glass available in the market and care should be taken to see that the right type of glass is used for the various types of construction. Nowadays, most of the glass produced in India is made by the float process, which produces excellent quality glass. However, cost should be the main consideration in choosing the glass and expenditure more than what is necessary, (depending on the type of building being constructed) should not be made in glazing work of a building.

REVIEW QUESTIONS

1. Indicate the types of glass used in ordinary buildings. What are the principal properties to look for in the inspection of glass to be used for glazing of buildings?

2. Write short notes on:
- (a) Laminated glass
- (b) Testing of glass for glazing for ordinary buildings
- (c) Solar control of glazed buildings
- (d) Obscured glass

(e) Float glass
(f) Sheet glass
(g) Greenhouse effect

3. Compare the manufacture of sheet glass, plate glass and float glass. Explain the factors to be taken into account in glazing of rooms that are to be air conditioned.

4. What are the following glasses and where would you use them:
(a) Laminated glass
(b) Frosted glass
(c) Glass blocks
(d) Wired glass
(e) Tinted glass.

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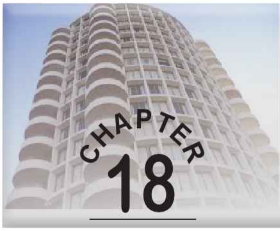


Chapter 18

Cast Iron and Steel

18.1 INTRODUCTION

Cast iron and steel are alloys of iron and carbon. Other alloying elements like copper, manganese, nickel, tungsten, etc. may also be added to steel to make special steels. Iron is a chemical element. Steel is iron containing less than 1.5 per cent carbon. Cast iron is different from steel in the sense that it contains more than 1.5 per cent carbon. Wrought iron is different from steel as it contains less than 0.15 per cent carbon. As the process of manufacturing of iron and steel is well known, we will deal only with the principles involved in its manufacturing and use. *In a historical sense, before the invention of steel by Bessemer in 1857, structural columns were made of cast iron, strong in compression and beams were made of wrought iron, strong in tension.* With the development of open hearth process and electric furnaces, now we are able to produce good steel *which is strong both in tension and compression*. In the present day practice, wrought iron has been more or less completely replaced by steel.

18.2 MANUFACTURE

As the manufacturing details of cast iron, steel and wrought iron are taught in schools they are not detailed here. We will only review it in short as follows. Iron ore is mined from earth and smelted in *blast furnace* to produce pig iron which is an impure product, weak in tension. It is converted into cast iron by mixing various other grades of iron so as to form the required composition and melting it down. This is done in a furnace called *cupola*. Pig iron is converted to wrought iron by the *puddling process*. Wrought iron does not harden suddenly when cooled, so that it can be made into different shapes when it is still hot. Steel is a later invention and is produced from pig iron by anyone of the processes, such as *Bessemer converter process* or *acid open hearth process* or *basic open hearth process*. The approximate percentage of carbon in the three basic forms of iron is as follows.

Cast iron	2 to 5% carbon (Specific gravity 7.2)
Steel	up to 1.5% carbon (Specific gravity 7.8)
Wrought iron	0.05 to 0.15% carbon (Specific gravity 7.7)

Carbon in excess of 1.5 per cent does not combine with iron, but will be *present as free graphite*. Thus, the dividing line of cast iron and steel is the presence of free graphite. If there is free graphite, then it is cast iron, otherwise it is steel. Steel becomes harder and more brittle with higher carbon content. Steel and wrought iron can be distinguished by putting a drop of nitric acid on the material. Due to higher carbon content than in wrought iron, it will produce a grey stain on steel.

18.3 IRON-CARBON ALLOYS

Iron and steel are not homogeneous like glass. Its composition can be compared to that of granite which has grains and crystals of differing compositions. The following are the different forms in which iron can be present.

1. ***Ferrite (α iron).*** It is pure iron, soft, ductile and malleable. It can hold carbon in solution only to about 0.04 per cent at 723°C and 0.006 per cent at 200°C. Wrought iron is about 90 per cent ferrite. It is a good conductor but at about 800°C, it becomes paramagnetic.
2. ***Cementite.*** It is iron carbide, Fe_2C. It is very hard and brittle. White cast iron has a good amount of cementite.
3. ***Pearlite.*** It contains about 0.85 per cent carbon. It is an aggregate made of alternate layers of small crystals of ferrite and cementite. Steel of this composition is the strongest because of the absence of large crystals of ferrite and cementite.
4. ***Austenite (γ iron).*** It is a *solid solution* of ferrite and cementite in each other. It remains in that state until it cools down to 1350°C slow cooling converts it to Ferrite and Pearlite. It is non-magnetic and resists wear but is not brittle.
5. ***Martensite.*** It is the chief constituent of *rapidly-cooled steel.* It is strong, hard and brittle. It is imperfectly preserved austenite.
6. ***Sorbite.*** This is imperfectly resolved pearlite.

Note: Thus, there are different types of iron with different carbon content. α iron and γ iron are allotropic forms which mean existence of iron in two separate crystal forms. A temperature of 723°C as shown in Figure 18.2, is the temperature at which the solid solutions will completely get separated into solid crystals.

18.3.1 Manufacture of Thermo-mechanically Treated (TMT) Bars

With the above background, let us examine what happens when a red hot steel rod emerging from the rolling mill is cooled suddenly by quenching with water and annealed under controlled conditions. It is shown in Figure 18.1(a).

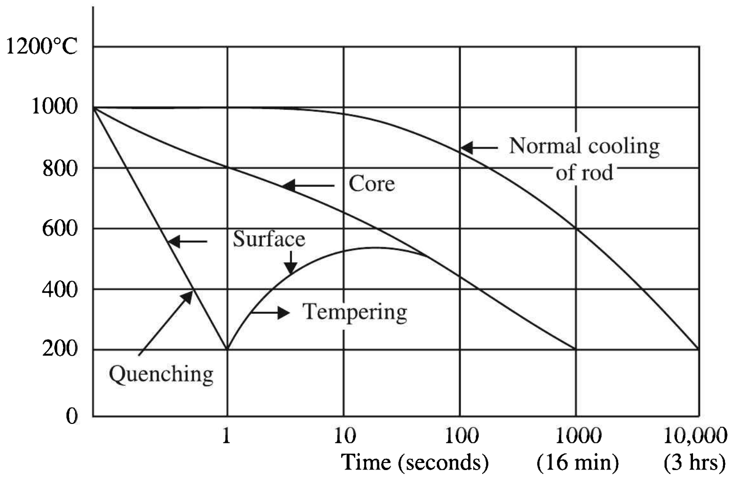


Figure 18.1(a) Quenching and tempering for production of TMT bars.

In the rolling mill, the whole section of the rod consists of austenite. Sudden cooling produces a surface layer of martensite which when cooled under controlled conditions becomes tempered martensite on the surface. As the inside is still hot and cools slowly, ferrite and pearlite are formed at the interior as shown in Figure 18.1(b). This is the process of producing the most modern TMT bars (Thermo-mechanically Treated bars) described in Section 19.2.3. The success of the process depends on the controlled cooling and tempering. It is the presence of the very strong material on the surface that gives the rod the high strength and the soft material inside that gives the rod its ductility.

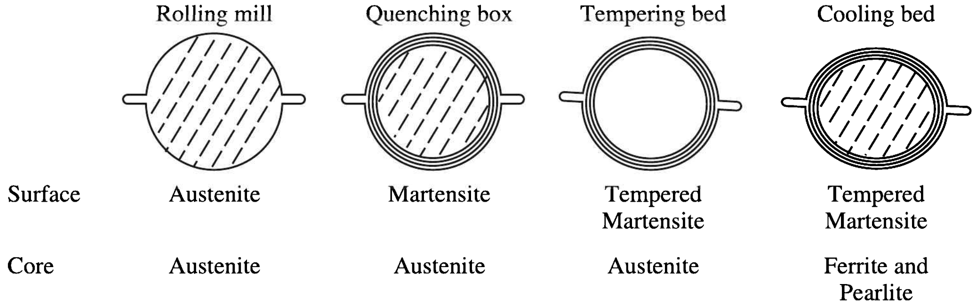


Figure 18.1(b) Production of TMT bars.

18.4 EQUILIBRIUM DIAGRAM (IRON-CARBON PHASE DIAGRAM)

The term *eutectic* is derived from Greek and it means the lowest melting point. A mixture in which the melting point is lower than its components is called a eutectic. Iron-carbon mixture forms different compounds with different proportions of carbon at various temperatures. An equilibrium diagram of iron-carbon alloys as shown in Figure 18.2 can be used for the study of the constituents present in the form of crystals or grains on cooling a molten solution of iron and carbon. The equilibrium diagram shows how iron-carbon alloy with less than about 1.5 per cent carbon forms into steel and with more carbon, we get *white cast iron.*

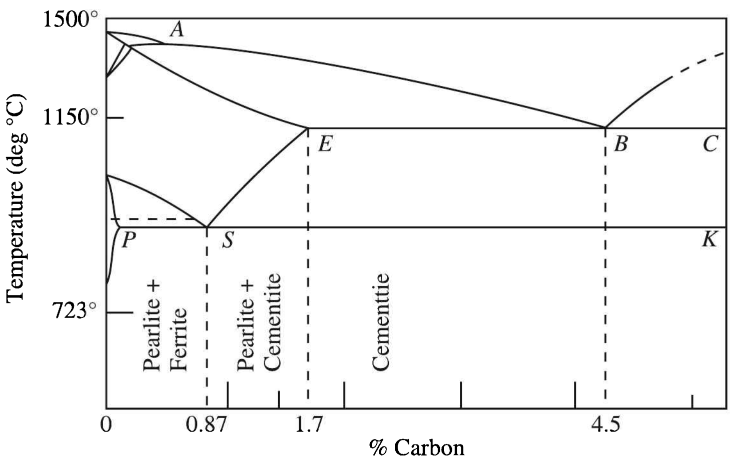


Figure 18.2 Iron-carbon phase diagram.

The iron-carbon phase diagram, as shown in Figure 18.2, indicates the decomposition of crystals of the solid solution. For our limited study, the diagram can be viewed in two sections. First section is *steel,* containing up to a maximum of 1.7 per cent carbon and the second section is cast iron, containing between 2 to 4.5 per cent carbon. Steel itself is divided into two types—Mild steel which contains only 0.15 to 0.3 per cent carbon and high carbon steel, which contains higher percentage of carbon. Thus, structural steel usually contains only about 0.25 per cent carbon whereas spring steel has 0.75 per cent and tool steel as much as 0.90 per cent carbon. The left hand side (below 1.7 per cent carbon) belongs to steel with eutectic. The right hand side (above 1.7 per cent carbon) with high carbon content and containing the eutectic belongs to cast iron. We can identify the following cases:

Case (i): Alloy containing about 0.35 per cent carbon give ferrite and pearlite on cooling.

Case (ii): Alloy containing 0.87 per cent carbon will be completely pearlite when cooled.

Case (iii): Alloy containing 0.87 to 1.7 per cent carbon will give pearlite and cementite on cooling.

Case (iv): Alloy with more than 1.7 per cent carbon will become cast iron on cooling consisting mainly cementite. This is white cast iron. *Grey cast iron is formed when 0.75 to 1.25 per cent silicon is also present in the alloy.* Then, some or all of the cementite breaks down to iron and graphite.

18.5 OTHER FACTORS IN MAKING IRON PRODUCTS

There are many other factors that affect the manufacturing of iron and steel. Some of them are discussed here.

18.5.1 Effect of Rate of Cooling

Slow cooling produces coarse pearlite structure while rapid cooling produces a fine pearlite. The tensile strength of *ferrite* is about 250 N/mm^2 and that of *coarse pearlite* is about 700 N/mm^2 whereas that of *fine pearlite* (formed by rapid cooling) is as high as 1300 N/mm^2. In the same way, if steel is cooled very rapidly from high temperatures, then there will be little time for austenite to transform to pearlite and a new material called martensite is formed. This material is extremely hard and brittle but can be modified by subsequent heat treatment. This material is used in the manufacturing of modern TMT bars used in reinforced concrete as shown in Section 18.3.

The $\gamma - \alpha$ iron transformation temperatures are called critical temperatures. Thus, the line PSK corresponds to the lower critical temperature and the line EC to the higher critical temperature. Presence of manganese and nickel lowers the critical temperatures while that of chromium raises the lower critical temperature.

18.6 MECHANICAL WORKING (TREATMENT) OF STEEL

One of the very desirable qualities of steel as different from cast iron is that it can be *hot worked* into different shapes. It can also be *cold worked* as well as *heat treated* to give desirable properties. All three operations are important and we should be aware of them.

18.6.1 Hot Working of Steel

For this purpose, the steel ingots are heated to the required temperature and the operations involved are the following:

(a) Rolling
(b) Forging
(c) Pressing
(d) Drawing

Of all the operations, rolling and drawing are the most important operations. Rolling is carried in specially-prepared rolling mills. The red hot ingots are passed through different rollers until articles of the desired shapes like I, L or angles are got.

In drawing, the metal is drawn through different dies and specially-shaped tools. It is with this process that the reinforcement rods are prepared.

18.6.2 Cold Working of Steel

From the stress–strain curve of mild steel shown in Figure 18.3, we find that if a steel bar is stressed beyond its yield point and unloaded, in the next cycle of loading, it will be found that the yield point has been raised. This is due to strain hardening of steel. However, this higher yield point is lost and the steel is restored to normal steel if we heat the bar to a high temperature (500–650°C) after cold working. Cold twisted deformed (CTD) bars for concrete reinforcement are produced by this principle. The cold working is carried by twisting the bar beyond the yield point. Welding of these bars should be done with great care as otherwise its high strength will be lost due to the heat.

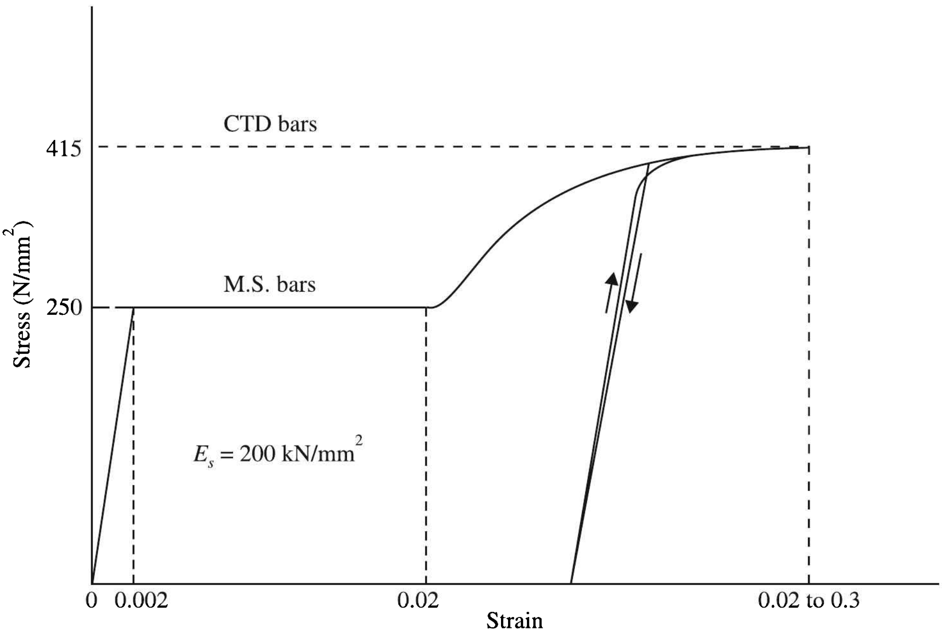


Figure 18.3 Stress–strain curve of mild steel. Raising of yield limit by cold working.

18.7 HEAT TREATMENT OF STEEL

Heat treatment is the process by which the steel is heated and cooled under controlled conditions to change the structural or physical properties of the steel. For example, we can increase the surface hardness of steel by *surface hardening* or *case hardening.* Tools, dies and a number of other components are case hardened before use. The common heat treatment processes are the following: (There are many other special techniques which is a special subject in metallurgy and these are not dealt with in this chapter.)

1. Annealling
2. Case hardening
3. Quenching
4. Tempering
5. Normalizing

Annealling. In annealing, the steel is heated to the required temperature which depends on the percentage carbon content of steel. The temperature is maintained for specified time and then, allowed to cool slowly in a furnace. Annealling has three purposes:

1. Relieving any strain produced in the steel during the welding
2. Restoring the grain structure to that minute size which gives the best quality
3. Softening the steel after hardening. The temperature used for true annealling is 700 to 1000°C.

Case hardening. Case hardening is one of the surface-hardening processes. It increases the carbon content at the surface. This process is required for components like of gears, bearing surface which requires to be tough and capable of carrying higher stresses. Steel used for this treatment is low carbon steel and the process increases the carbon content of the outer case. A carbonizing mixture (charcoal, cyanide, etc.) is used for this purpose. The article is held in the mixture and heated to 900–950°C when the carbon diffuses into the surface of the article. This temperature is kept for 6 to 8 hours after which it is cooled slowly to normal temperature. It is a specialized process requiring special knowledge. This process has many applications in industry. *However, for critical components as for use in lifting very heavy weights, it is better to use special strength alloy steel than increase hardness by case hardening*. It is because it is difficult to get reliable case-hardening operations carried out locally and any mishap can lead to very serious consequences.

Quenching for hardening. If steel is heated to high temperature (critical temperature depending on composition of steel) and suddenly quenched by pouring water or dipping it in oil, then the steel becomes harder as well as stronger and more brittle. This is due to surface formation of *martensite* which is stronger and harder than mild steel. This principle is also used in the manufacturing of thermo-mechanically treated (TMT) steel bars for reinforced concrete [Figure 18.1].

Tempering. Hardened steel produced by quenching is too brittle to be used without some tempering. It has to be tempered. During this process the steel is heated to 200–700°C when quite a little of its brittleness and part of the hardness will be lost and the steel is fit in use in engineering purposes (annealling involves higher temperatures). It will remove a large part of internal stresses produced in quenching. The higher the temperature used in tempering, the greater will be the reduction in hardness and increase in toughness.

Normalizing. This is also a heat treatment of steel in which the steel is heated to about 40°C more than the annealling temperature and then allowed to cool down in still air to room temperature. In this process, the rate of cooling is faster than in annealling. Hence, it gives finer pearlite structure. The steel is relatively soft and ductile but harder than the annealled material.

18.8 MILD STEEL AND OTHER STEELS

There are many types of steel. Mild steel (structural steel), tool steel, machinery steel, high tensile steel and special steels are some of them. They differ in their carbon content, ultimate strength, yield point, per cent elongation at ultimate failure, Brinell's hardness, etc. The distinguishing property of mild steel can be taken as the nature of the stress-strain curve. Generally, its yield strength is 250 N/mm^2, it reaches strain hardening strength at about 1.6 times its yield strength (about 340 N/mm^2) and ultimate failure strength can be of the order of 550 N/mm^2 (Figs. 18.3 and 19.2). Above all, we must note that the percentage of elongation of mild steel at ultimate failure is as much as 30 per cent. Thus, mild steel is very ductile compared to all other types of steel used for engineering purposes. Steels like high tensile steel and prestressing steel have higher yield points which are obtained only at the expense of decreased percentage of elongation at ultimate failure. Ductility is measured by the percentage of elongation at failure. Ductility is a very important property for steel rods to be used in reinforced concrete design for earthquakes.

18.9 WROUGHT IRON

As we have discussed earlier, wrought iron contains less than 0.15 per cent carbon. It is made from white pig iron by removing most of the carbon, manganese, silicon, phosphorous and sulphur by the puddling process in a reverberatory furnace. Being equally strong in tension and compression, steel has nowadays replaced wrought iron in common use. A small amount is used for making tough articles like spikes, nails, bolts and nuts, chains, handrails ornamental gates, straps for timber roofs, pipes tubes, etc. Wrought iron fence-posts are commonly used for ornamental purpose.

18.10 CAST IRON

We have already discussed what cast iron is. It is about three to five times stronger in compression than in tension. Its strength in compression is about 560 N/mm^2 and its strength in tension is only about 140 N/mm^2. Carbon lowers the melting point of iron, so cast iron melts at lower temperature than steel. Hence, it is easier to make castings of cast iron even in small factories. Its melting temperature is about 1200°C whereas that of wrought iron is above 1500°C. Grey cast iron, whose fracture has a grey colour due to precipitated carbon (graphite), is extensively used for casting. It has a coarse crystalline structure and melts readily. White cast iron shows white fracture, and is not used for delicate castings (See Section 18.4).

Cast iron is still used very much in industry where the forces are in compression and the structural part does not have to withstand shock, bending and tension, etc. Cast iron is cheap as it is capable of manufacture with simple tools in small factories even in remote corners. Unlike steel, cast iron is very resistant to corrosion and extensively used in rainwater pipes, flushwater cisterns, etc. Cast iron pipes are centrifugally spun and available in various sizes up to 3 m in length.

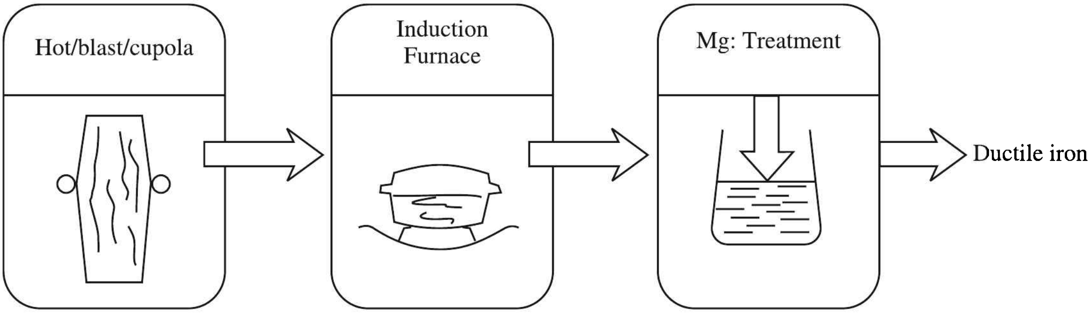
18.10.1 Malleable Cast Iron

Many small parts were once made of malleable cast iron. Articles like prestressed concrete sleeper fastenings for rails of the Indian Railways were formerly made of malleable cast iron. It is manufactured as small casting by the process called "malleable cast iron process". The aim of the process is to extract a portion of the carbon from the cast iron and make it less brittle than cast iron. In this process, the individual castings are first cast and cooled as ordinary white cast iron. It is, then, heated to about 1050°C and "soaked" for several hours or days. Then, it is cooled slowly. In this process, the combined carbon is reduced and graphite is precipitated as "temper carbon". Malleable cast iron can be machined easily and it get deformed without rupture. It can endure many batterings without cracking and has better corrosion qualities. Hence it is used as inserts with prestressed concrete sleepers by the Indian Railways. However, due to difficulties in manufacturings these fastenings are now being made from "spheroidal graphite iron" or "ductile iron" which is described below.

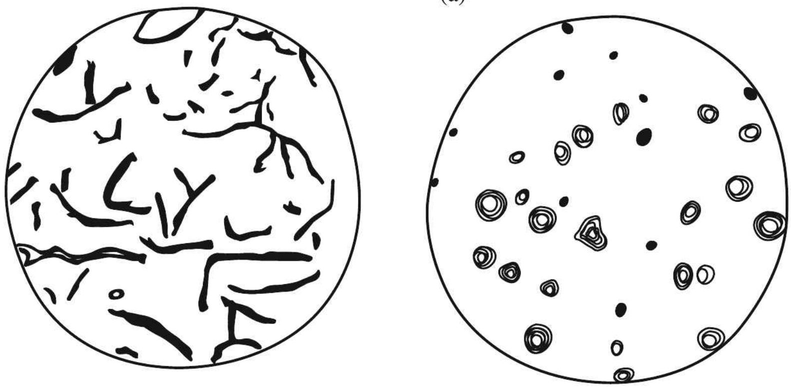
18.10.2 Spheroidal Graphite Iron (Ductile Iron)

Manganese has the property to increase the content of carbon in iron and oppose the formation of free graphite in flaky form. Thus, the presence of flaky graphite in cast iron can be prevented and carbon is reduced to spheroidal form. Hence, it is called spheroidal graphite iron. This product has less brittleness. Nowadays, this material is commonly used instead of malleable cast iron as in railway sleeper inserts, etc. It is easier to manufacture spheroidal graphite iron than malleable cast iron. The manufacture microstructure of grey cast iron and ductile iron are shown in Figure 18.4.

Unlike malleable cast iron, large articles can also be made from ductile iron. Traditionally, cast iron pipes were used for carrying water and sewage as they are more resistant to corrosion than steel pipes. These pipes are now being replaced by ductile cast iron pipes which have high strength, ductility and also good corrosion resistance. Cast iron pipes being weak in tension are liable to be damaged when there is settlement along its length whereas ductile cast iron can stand small settlements without damage. As ductile iron can be cast into any shape, it is nowadays used extensively instead of steel for making items complex machining operations and a material like steel. Ductile iron also has high corrosion resistance like cast iron.



(a)



(i) (b) (ii)

Figure 18.4 (a) Manufacture of Ductile Iron with Magnesium treatment. (b) Microstructure of (i) Cast iron (ii) Ductile iron.

18.11 CORROSION RESISTANCE OF CAST IRON

Grey cast iron pipes buried in soil have been found to not been corroded even after a period of 150 years. In the corrosion of grey iron at the surface, say of a buried pipe, the graphite present will be left as a residue within the corrosion products which adheres very firmly to the unattached metal substrata. This graphite containing corrosion product provides a barrier against further corrosion attack if it remains undisturbed as in buried pipes. Thus, the graphitic corrosion residue incast iron can limit the rate at which further attack can occur. However, this residue is much less in strength than the original cast iron. But if left undisturbed, the pipe can work for a very long time.

SUMMARY

There are many products made of cast iron and steel used in construction of buildings. Engineers should be aware of the different products and treatments that are available for the material.

REVIEW QUESTIONS

1. Explain the difference between wrought iron, steel and cast iron. What are the distinguishing features of mild steel? Why is it easy to make C.I. castings?

2. Write short notes on hot working, cold working and heat treatment of steel giving examples of each. Explain the principle of making CTD bars for use in reinforced concrete construction.

3. Explain the principles of manufacture of TMT reinforcement bars for reinforced concrete construction.

4. What are the different types of heat treatment of steel and their uses?

5. What are malleable cast iron and ductile iron? What are their uses?

6. Explain why cast iron pipes are more resistant to corrosion than steel pipes?

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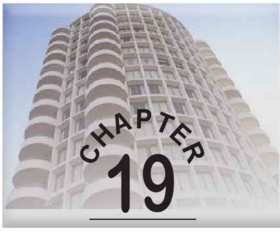


CHAPTER 19

Market Forms of Steel

19.1 INTRODUCTION

The important market forms of steel used in building construction are the following:

1. Steel bars of many shapes and grades or strengths. (These bars are used for R.C. and also for fabrication of grills, gates, etc.)
2. High tensile steel for prestressed concrete works.
3. Various shapes of I, channel, angle, plates and other rolled sections for structural fabrication.
4. Cold formed light gauge structural steel sections.
5. Stainless steel for special uses.

In this chapter, we will deal with steel reinforcements used in reinforced concrete construction in some detail and others very briefly.

19.2 TYPES OF STEEL REINFORCEMENT

Steel rods used for reinforced concrete work should be of specified tensile strength, and they should develop good bond strengths with concrete. There are different types of steel like mild steel, torsteel, TMT bars available in the market, and one should be able to identify them by sight. Steel rods of different diameters are used for R.C. work. In order to identify the sizes easily, only standard sizes should be used in building units. Prices depend on bar sizes. Basic price is for 16 mm bars, sizes below 16 mm costing more and sizes above 16 mm costing less. The following types of bars are commonly available in market for reinforced concrete construction.

1. Hot rolled bars, of which there are four types (Figure 19.1):
   - (i) Hot rolled plain round *mild steel bars* (MS bars)
   - (ii) Hot rolled ribbed mild steel bars (generally not recommended for use)
   - (iii) Hot rolled *high strength deformed bars* (bars like Tistrong bars by Tisco) also called as HYSD bars (high strength got by micro alloying)
2. Hot rolled *cold twisted deformed bars* like Torsteel (CTD) bars (high strength got by cold twisting)

3. *Thermo-mechanically Treated* (TMT) bars (high strength got by controlled cooling)
4. Cold drawn steel wire fabric (welded wire fabric).

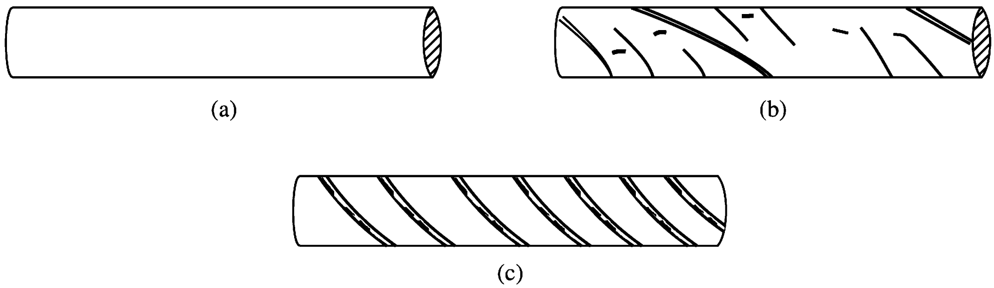


Figure 19.1 Profiles of reinforcement bars (a) M.S. bars (b) Torsteel bars (c) Rolled ribbed bars and TMT bars.

19.2.1 Hot Rolled Bars

First, we will examine the three types of hot rolled bars (see Figure 19.1).

(a) The first type of hot rolled bars is the traditional mild steel bars (MS bars) produced by hot rolling. They are hot rolled as round bars with smooth surface. They are called *mild steel plain bars*. These bars when used as reinforcements are always to be hooked at their ends, (except at laps) for anchorage. Mild steel bars are divided into Grade I and Grade II. The strength of Grade II bars is slightly lower than that of Grade I. These bars are more resistant to corrosion than torsteel bars. With the advent of stronger bars, these bars are not nowadays very much used in construction, except under special circumstances as for fullyexposed fencing posts, etc.

(b) The second type of hot rolled bars that was developed is the hot rolled *mild steel ribbed bars*. It is possible while rolling steel rods to produce ribs on them. These ribs considerably increase the bond strength of the bars. Such ribbed bars in mild steel, even though not recommended in the code, are sometimes made available in the market; and one should be very careful not to confuse them with hot rolled high strength ribbed bars. The allowable stresses in these mild steel bars with ribs (even though they look like high strength hot rolled ribbed bars) are much lower than that allowed for true ribbed bars described below. (Bars with ribs are called Rebars or ribbed bars.) As they are likely to be confused with HYSD bars, described below, these bars should not be used in R.C. works.

(c) The third type of bars are the "*hot rolled high strength ribbed bars*" where the high strength is got by micro alloying. These bars too are produced by hot rolling. However, steel being an alloy, with the addition of certain substances in steel, rearrangement of the grains takes place in the final product and steel with much higher tensile strength than ordinary mild steel can be produced. To take advantage of the high strength special, surface deformation are specified to be given to these bars while rolling. These rods are known as the hot rolled "high yield strength deformed bars" or HYSD bars. These bars are now being replaced by TMT bars.

Determination of diameter of deformed bars. As deformed bars have projecting ribs, their diameters cannot be measured directly. It is determined by cutting a given length of the rod and weighing the piece. The diameter is determined from its weight assuming the specific gravity of steel as 7.85.

19.2.2 Cold Twisted Deformed Bars (CTD Bars–Torsteel)

Cold twisted deformed bars were the first high strength bars introduced in India around 1960. These bars are first hot rolled out of high grade mild steel, with three or more parallel straight ribs and other indentations on it. After cooling, these bars are twisted by a separate operation so that the steel is strained beyond the elastic limit and then released. This operation raises the yield point of steel for subsequent tensile or compressive stresses and thus, its strength is increased as already shown in Fig. 18.3. As the increase in strength is due to cold working, this steel should not be normally welded. If welding has to be done, then care should be taken to follow strictly the special instructions for welding of cold twisted bars. In all cases, overheating above a certain temperature should be avoided.

Cold twisted bars can easily be identified in the field. As the projections were rolled straight on the bar in hot rolling, they will form a helic around the bars while cold twisting. Thus, by examining the deformation, one can distinguish between the hot rolled and cold twisted high bond bars. The bars can also be examined for efficiency in twisting by measuring the pitch as shown in Figure 19.1. If the pitch is too close, then it is over twisted. Cold twisting introduces residual stresses in the steel. Hence, these bars corrode much faster than other bars. According they are not recommended for use in many advanced countries.

19.2.3 Thermo-mechanically Treated Reinforcement Bars (TMT Bars)

The recent introduction of TMT bars requires special mention. As already stated in Section 18.3.1, sudden quenching of red hot steel bars by a spray of water (as it is being rolled in the factory) can produce steel bars with high strength at the surface with a core of mild steel. As the core of the wire is still hot, the heat inside helps in tempering the surface. The result is a structure with *tempered martensite* on the periphery and a fine grained *ferrite-pearlite* structure at the centre zone. The combined strength of these materials raises the yield point of steel with the high percentage of elongation at ultimate failure. These bars are also rolled with ribs (rebars) to increase their bond strength. Such bars are now being produced in India and are called TMT bars. Higher strength than mild steel bars are allowed in design for these bars also. Their performance with reference to corrosion resistance is better than that of cold twisted bars.

Special TMT-CRS (corrosion resistant) steel bars are also sold in the market. Corrosion resistance is achieved by addition of corrosion resistant elements like copper, phosphorous and chromium. However, the claim is only that these bars are more corrosion resistant than other torsteel bars. Hence, all precautions against corrosion should be adopted even while using such bars for reinforced concrete. These bars are produced in three grades—Fe415, Fe500 and Fe550.

19.2.4 Welded Wire Fabrics

These are known as fabrics and consist of weld mesh made from medium tensile steel drawn out from higher diameter mild steel bars. As the steel wires are *cold drawn*, they undergo “cold working” and the strength of these wires is higher than that of mild steel. These wires are then spot welded in a machine into weld mesh. They are available in different widths in rolls. They are used in India to a limited extent, even though they were very popular once for R.C. slab construction. Nowadays, they are very much used in partitions, fencing, etc.

19.2.5 Standard Sizes of Bars (IS 1986–2009)

Even though bars can be rolled into any size, the thirteen nominal standard diameters according to IS 1786–2 for reinforced concrete construction are 4, 5, 6, 8, 10, 12, 16, 20, 25, 28, 32, 36 and 40 mm. These thirteen sizes have the advantage that they can easily be distinguished from each other in the field by visual inspection and also the cross sectional area corresponding to each diameter is approximately equal to the sum of the cross sectional areas of the two proceeding lower bar size so that all combinations of areas can easily be made from them. Bar sizes 6 to 16 mm are used in slabs while 12 to 40 mm bars are used in beam and column construction. (Note: $6^2 + 8^2 = 10^2$)

It should be remembered that as it is difficult to measure the size of a deformed bar by field calipers, the nominal size of a deformed bar is taken as the equivalent diameter of a smooth bar having the same weight per unit length as the plain bar. The tolerances on the weight of bars usually allowed are, for bars 8 mm and below ±4 per cent and for bars over 8 mm ±2.5 per cent.

19.2.6 Steel for Reinforced Concrete Construction

The grades of the reinforcement bars is indicated by its yield or proof strength. Thus, bars are designated as Fe250, Fe415, Fe500, Fe550. The symbol Fe denotes that it is steel reinforcement. The figures following the symbol indicates the *yield strength or in steel without a definite yield point, the specified 0.2 per cent proof stress in N/mm^2. Proof stress is the stress at which the non-proportional elongation is equal to 0.2 per cent of the original gauge length*. The ultimate strength is the failure strength of the material. The revised IS 1986 (2008) code has also introduced a special variety called "ductile type" in grades 450, 500 and 550. Thus 450D means grade 450 steel of ductile variety. The specified properties of the various grades are given in Table 19.1. The following two tests are generally specified.

1. ***Tension test of reinforcement bars.*** Tension test is an important test prescribed for steel (See Figure 19.2). The following important physical quantities can be measured

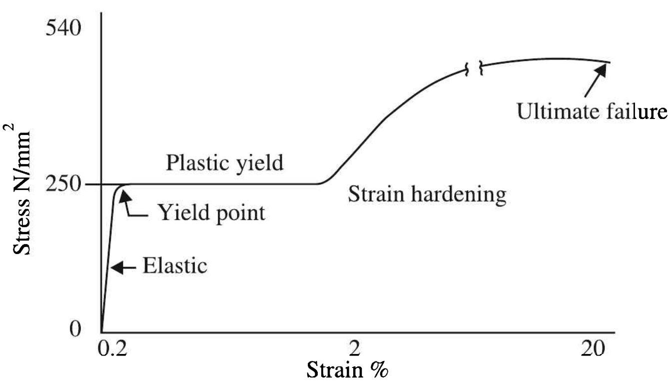


Figure 19.2 Tension test on M.S. bars (16 mm dia.).

by a tensile test in a testing machine. A gauge length used for the test is 5.65 times the square root of the cross sectional area of the test piece.

(a) Yield strength or proof stress
(b) Ultimate tensile strength
(c) Elongation at failure is percentage elongation at failure.
(d) A new term per cent total elongation at maximum force has been introduced in the 2008 revision of the code. It is the uniform elongation corresponding to the maximum load in the test.

The values given in Table 19.1 are the approximate values of the important properties for the different types of steel.

Table 19.1 Specified Mechanical Properties of Deformed Bars (Ref Table 3 of IS 1786 (2008))

Type of bars	Yield/proof stress N/mm^2	Ultimate tensile stress N/mm^2	Elongation at failure (%)
Fe 250	250	410	23.0
Fe 415	415	485	14.5
Fe 415D	415	500	18.0
Fe 500	500	545	12.0
Fe 500D	500	565	16.0
Fe 550	550	585	10.0
Fe 550D	550	600	14.5
Fe 600	600	660	10.0

Note. For all D grades the total elongation at maximum force, per cent on standard gauge length should not be less than 5.

2. ***Bend test and reverse bend test for reinforcement bars.*** In addition to the tensile test, the bend test and the reverse bend test are also prescribed to test the quality of R.C. bars. These tests are prescribed in IS 1599. Of these tests, the reverse bend test is more commonly prescribed. It is preferable to conduct these tests in a testing machine as shown in Figure 19.3.

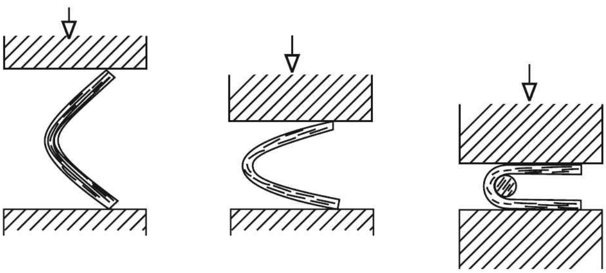


Figure 19.3 Simple bend test.

In the *simple bend test*, the bar is bent completely around a mandrel of diameter 4*d* for bars up to 22 mm and 5*d* for bars over 22 mm. There should be no fracture under this test.

In the *reverse bend test* the bar is first bent to an included angle of 135 degrees around a *mandrel* (5*d* for rods up to 10 mm diameter and 7*d* for rods over 10 mm diameter, where *d* is the diameter of the bar). The bent bar is aged by keeping it in boiling water for 30 minutes and then allowing to cool. The bar is then bent back to have an included angle of 157.5 degrees. If there is no fracture in the bent portion, then the specimen passes the test. One reverse test is prescribed for every 3 to 5 tonnes of steel. *Retest* is allowed on *two further samples* if the specimen fails. If any of the retests fails, then the steel is to be rejected. If both of the retests pass, then the steel is considered as fit for use.

These tests are meant to check the ductility of the rerolled bars.

19.2.7 Storing of Reinforcements

Steel bars should be stored properly to avoid corrosion and distortion by keeping them off the ground and providing enough support so that they do not bend. If they are to be stored for long periods, then some cover should be provided to keep off the rain. Slight rusting of the surface of steel is allowed in steel bars, but bars that have scales of trust must be cleaned off these rust before being cut and bent. It is not a good practice to cement wash steel, as the grout dries quickly and gets scaled off as powder. It is difficult to keep off rust in steel if they are to be stored near the sea in coastal areas. Bars of separate diameters should be stored as separate lots. Usually, bars, as they are rolled in the factory are cut and sold in the market in lengths of 6 to 7 metres (20–24 feet).

19.2.8 Need for Inspection of Reinforcement before Using in Actual Work

All reinforcements for R.C. construction should be free from paint, oil, grease, loose rust, loose mild scale and any other matter likely to impair the bond strength of the concrete. Oil can be removed by thoroughly washing with petrol. Steel so treated should be left in the open for a few days and then, brushed with a wirebrush before it is used. The rods when bent into hooks should not crack or split as it will indicate a brittle steel. If there is any doubt about the quality of the steel, then the test certificates from the steel factory should be obtained or it should be tested in an approved laboratory. The report should contain data regarding yield strength, ultimate strength as well as percentage elongation at failure and percentage reduction in area at point of failure. Results of the bend test will also be useful.

19.3 STEEL FOR PRESTRESSED CONCRETE

We have to use *high tensile steel* for prestressed concrete construction. The ultimate strength of these steels will be of the order of 1400 to 1700 N/mm^2. High strength can be produced by alloying steel with carbon, manganese, silicon, etc. The more common method of increasing the tensile strength of such steels for prestressing is by cold drawing. In this process, the high tensile bars are cold drawn through a series of successive smaller dyes. Cold drawing tends to realign the crystals and the strength is increased by each drawing so that the smaller the diameter of the wire, the higher will be its *ultimate strength*. The yield point also goes higher. However, ductility of the wires, is decreased as the difference between strain at yield point and ultimate failure point decreases. However, a minimum ductility as percentage of elongation at failure is always prescribed for all such steels.

These high tensile steel usually takes one of the following three forms—bars, wires and strands made up of wires. For post-tensioning, the small diameter wires are made into cables. Heat treatments are also made to relieve the wires of built-in stresses. Such wires are called *stress relieved or annealled high tensile wires.*

We should clearly understand that the prestressing bars or wires in prestressed concrete perform a function very different from the reinforcement in reinforced concrete. Their job in prestressed concrete is simply to stress the concrete and under normal working loads, the stress in the steel will remain more or less *constant and active.* In reinforced concrete, the steel will be stressed only when the structure is loaded and it is said to be *passive.* The stress in the steel will vary with the magnitude of the loading.

19.4 ROLLED SECTIONS—STRUCTURAL STEEL

The two main families of structural steel members are the following:

1. The conventional hot-rolled steel sections and
2. Cold-formed steel sections

19.4.1 Hot-rolled Steel Sections

Steel used for fabrication of trusses, column, beams, etc. of buildings is made by rolling hot steel ingots into various shapes in specially-designed rolling mills. Hot-rolled steel sections are illustrated in Figure 19.4. The sections that are popularly available are the following:

1. ***Angle sections.*** Various sizes of equal and unequal angle sections are available. They are mainly used for trusswork and filler joist floors.
2. ***Channel sections.*** Bureau of Indian Standards classifies channels as junior channels (ISJC), light channels (ISLC), and medium channels (ISMC). They are used widely for steel framed structures.
3. ***I sections.*** These sections are called *rolled steel joists* or beams. They are classified as junior beams (ISJB), light beams (ISLB), medium beams (ISMB), wide flanged beams (ISWB) and heavy beams (ISHB). They are used in multistoreyed buildings, bridge and other places where bending stresses are the maximum. The materials in the I sections are distributed so that the maximum material exists where bending stresses are the maximum.
4. ***T sections.*** These sections are used to make builtup sections and roof girders.
5. ***Other rolled sections.*** Plain sheets, corrugated sheets, plates, expanded metal, sheet piles, rail sections, flats of varying width and thickness, are also rolled in rolling mills. They are used for fabrication. In addition, special sections such as those for sheet piles, railway lines are also rolled in steel factories.

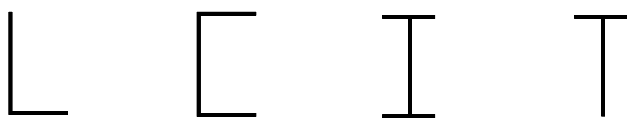


Figure 19.4 Hot-rolled steel sections.

19.4.2 Cold-formed Light-gauge (Thin Walled) Steel Sections

Cold-formed light-gauge steel sections are structural members, cold formed to the desired structural shapes from carbon or alloy steel (strips or flats) by press-brake operations. The thickness of the member ranges from 0.38 to 6.35 mm. Some of the structural shapes available in the market are shown in Figure 19.5. As these sections are made of alloy steel and they are cold formed, they have much higher strengths than hot-rolled sections.

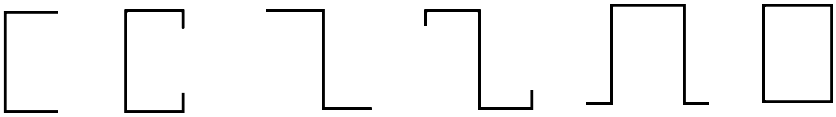


Figure 19.5 Cold-formed sections.

The advantages of the cold-formed sections over hot-rolled sections are the following:

1. When compared with the regular hot-rolled shapes, cold-formed sections are thinner so that we can get more length of the material from the same weight of steel. A more economical design for light loads and moderate spans can be made from these sections.
2. As effective shapes or configurations of steel sections can be produced by cold-forming operations, a more favourable strength-to-weight ratio can be achieved through these sections.
3. Aesthetically pleasing sections like box sections (resembling wood battens) are available out of this material for fabrication. With these sections and necessary painting or other treatments, the fabricated structure can be made to look as if made of wood.
4. Cold-formed steel sections have higher strengths than hot-rolled sections.
5. These are extensively used in fabrication of roof trusses.

19.5 STAINLESS STEEL

Stainless steel is a general term given to certain alloys of iron, chromium and nickel. This type of steel has high resistance to corrosion. They are designated by the percentage of chromium and nickel. Thus, 18-8 stainless steel indicates 18 per cent chromium and 8 per cent nickel.

SUMMARY

Steel in various forms is a very important material for building construction. Various types of reinforcement bars, prestressing wires and strands, rolled steel sections and light-gauge steel sections are the important forms of steel that are commonly used in building construction. Even though IS 1786 does not give any recommendations regarding the use of the various grades and types of steel, their actual use in the field should be based on past experience in a given situation.

REVIEW QUESTIONS

1. Give a brief account of the different types of steel bars used in reinforced concrete construction.

2. Write short notes on:
(a) Torsteel bars
(b) TMT bars
(c) Cold-formed light-gauge steel sections
(d) Rolled steel joists
(e) Reverse bend test for reinforcement bars
(f) Determination of the diameter of ribbed bars
(g) 18-8 stainless steel
(h) Yield stress and proof stress

3. Enumerate the two important tests that are generally specified for steel reinforcement bars for use in reinforced concrete.

4. What are the important market forms of steel available for building construction?

5. Explain the terms yield stress, proof stress and ultimate stress of steel reinforcement. What is meant by Fe500 steel?

6. How is prestressing steel different from the steel used for reinforced concrete. Compare their strengths and ductility.

7. How are light gauge steel sections made? What are the advantages of using them?

8. Describe a field test to check the ductility of reinforcement bars?

REFERENCES

[1] IS 432–1982: *Specification for Mild Steel and Medium Tensile Steel Bars and Hard-drawn Steel Wire for Concrete Reinforcement—Part 1, Mildsteel and Medium- tensile Bars; Part 2, Hard-drawn Steel Wire.*

[2] IS 1786–1985: *Specification for High Strength Deformed Steel Bars and Wires for Concrete Reinforcement.* (This has been revised as 1786–2008 (Fourth revision)

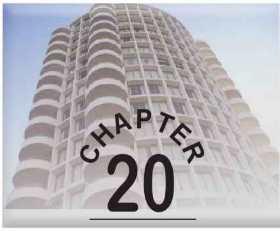
[3] IS 808–1989: *Dimensions of Hot-rolled Steel Beam Column, Channel and Angle Sections.*

[4] IS 811–1987: *Specification for Cold-formed Light-gauge Structural Steel Construction.*

[5] IS 1599–1985: *Method for Bend Tests.*

[6] IS 1608–1972: *Method of Tensile Testing of Steel Products.*

[7] IS 226–1975: *Structural Steel Specification.*



CHAPTER 20

Aluminium and Its Alloys

20.1 INTRODUCTION

Aluminium and its alloys are nowadays extensively used in building construction. For items like windows where wood was used earlier, we increasingly use aluminium products now. Since teak and other varieties of wood have become scarce and expensive, aluminium is a good alternative. Aluminium is also becoming popular as roofing sheets. The traditional method of laying wooden rafters and clay tiles is labour intensive and also difficult to maintain.

Aluminium is a relatively new material, and was at one time, costlier than platinum. Although the ore is abundantly available in the form of oxide, extraction of the metal became commercially possible only after the development of electrical power generation technology, since the process involves large scale electrolytic reduction.

The spectacular growth of aluminium consumption is the proof of the metal's contribution to the modern industry and the building industry. It is second only to iron in annual consumption, and is the most important non-ferrous metal. It has good resistance to atmospheric corrosion, and is very light, with a density one-third that of steel. However, its strength-to-weight ratio is high enough to be a favourable alternative to steel in many constructions.

Pure aluminium is very soft, ductile and malleable, easily rolled into sheets or drawn as wire. It can be cast, forged or extruded into complex profile shapes. Addition of alloying elements like magnesium, silicon, manganese, copper, and zinc can significantly improve its strength, hardness, and other properties, while retaining its lightness and durability. For example, about 1% addition of magnesium and silicon can lead to three-fold increase in strength. About 4% addition of copper and smaller amount of magnesium, silicon and manganese results in an alloy having strength comparable to steel, which is used in aircraft construction and for defence equipment.

One drawback of aluminium in many applications is its low modulus of elasticity (only 68 kN/mm^2 compared to steel having 207 kN/mm^2). This means that for a similar structure and loading, the elastic deflection will be about three times greater for aluminium compared to steel. The low elastic modulus can also be an advantage, where greater shock-absorbing capacity is required. This aspect must be examined in any aluminium structure design. Aluminium loses its strength at about 225°C, compared to 450°C for steel; hence, it is much less suitable for higher temperature applications.

Aluminium wire for power transmission has conductivity about 61% that of copper, while its density is less than one-third. For electric cables that have many applications, aluminium can be a lighter and cheaper alternative.

20.2 MANUFACTURE

The element aluminium in the form of oxide (alumina, Al_2O_3) comprises 15% of the earth's crust and is second only to silica in abundance. The most important ore is bauxite, which contains over 50% alumina. Extraction of metallic aluminium from the ore is done in three basic steps, namely, mining, refining and reduction.

The principles of aluminium extraction were developed in 1886 by Charles Martin Hall (USA) and Paul Heroult (France) but in 1888, Karl Bayer (Austria) established the modern process, which is in use today.

The manufacturing process is outlined in Figure 20.1, and can be described as follows:

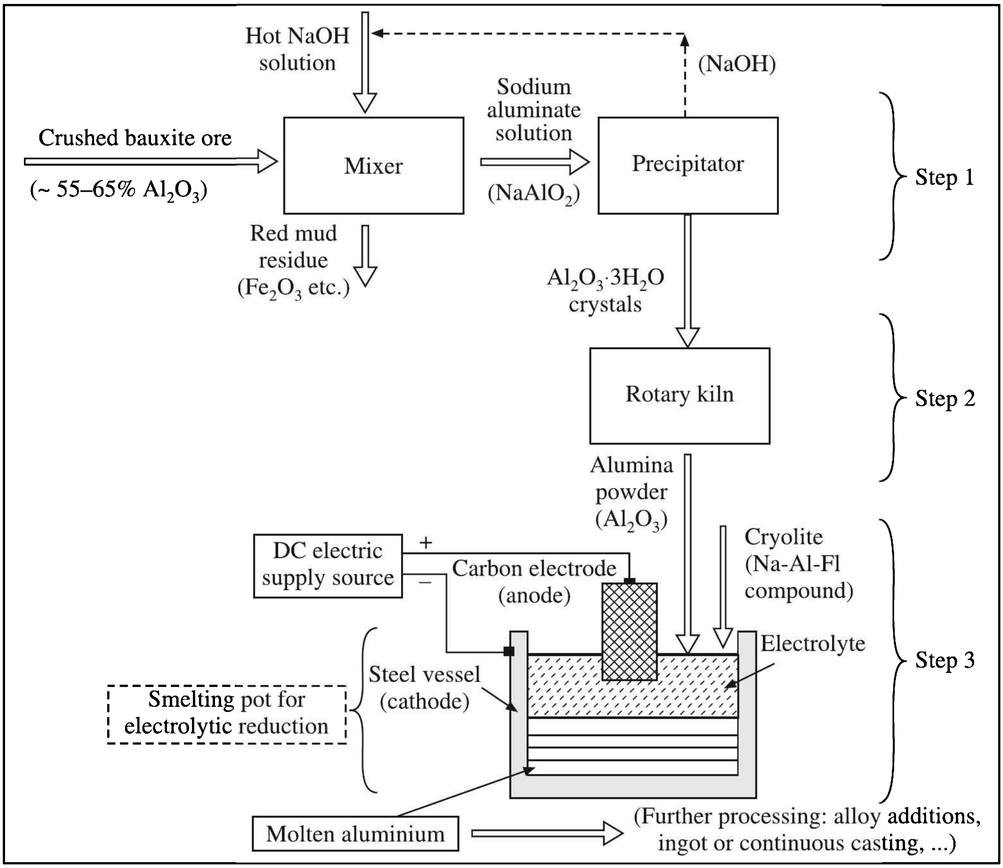


Figure 20.1 Basic steps involved in the manufacture of aluminium.

20.2.1 Description of the Process

Step 1—Mining

Crushed bauxite ore is first treated with a solution of hot caustic soda (NaOH) to dissolve alumina hydrate from the ore. The insoluble residue termed as *red mud* mostly containing oxides of iron and silicon is removed by filtration and decantation

Bauxite + Hot caustic soda = Sodium aluminate solution

Step 2—Refining

The hot sodium aluminate solution is pumped into precipitators, where it gets crystallized to $Al_2O_3{\cdot}3H_2O$. The precipitated crystals after size classification are filtered and fed into a rotary kiln, where the heat and mechanical tumbling convert the hydrated crystals into fine white alumina powder.

Step 3—Reduction

An electrolytic process is used for converting the oxide into metallic aluminium as follows:

Alumina is charged into steel vessels called *smelting pots*. Some quantity of cryolite, which is another mineral compound of sodium, aluminium and fluorine, must also be present in the vessel: but it does not get consumed. Carbon electrodes, which are dipped into the vessel, form the anode of the DC supply. The vessel shell forms the negative electrode (cathode). On passing electric current, the oxide gets reduced to molten aluminium, which forms a pool at the bottom, from where it is siphoned off periodically for further processing. The carbon anodes get consumed as the oxygen combines with carbon to form CO_2 gas. Suitable alloying elements are added to the molten aluminium.

20.2.2 Processing of Aluminium Metal

Before casting the metal as ingots, the molten aluminium is alloyed, if necessary, with other specified ingredients to impart special properties.

20.2.3 Conversion into Different Products

Aluminium slabs are rolled in rolling mills to get sheets and foils. The wire rods are drawn down to different sizes of wires. The billets are extruded to different shapes by forcing them to flow under suitable pressure and temperature through a die orifice, which is shaped to impart the required form of the product. As aluminium and many of its alloys are ductile, they can be extruded to exact and complicated sections with very tight tolerances. Many of the aluminium fabricators have their own extruded sections for fabrication of their items like windows, doors, façade for tall buildings, bus bodies, ladders, electrical appliances, etc.

20.3 IMPROVING SURFACE APPEARANCE

One of the advantages of using aluminium in buildings is that aluminium products can be given permanent attractive colours by the following two processes:

1. Anodizing
2. Powder coating

These are described below:

20.3.1 Improving Appearance by Anodizing of Aluminium

Rolled or extruded aluminium has a coating of a film of its oxide having a thickness of 0.005 to 0.15 μm (1 μm = 0.001 mm). This coating thickness can be increased to 10 to 25 μm by a process called *anodizing*. It consists of immersing the item in dilute sulphuric acid and passing electric current under controlled conditions. This coating improves the corrosion resistance and prevents further attack from other atmospheric agencies. Various dyes for colouring can be deposited in the anodized article by dipping the article in a suitable dye bath immediately after anodizing. The pores in the anodized surface get filled by desired colouring constituent. IS 1868 deals with anodizing of aluminium.

20.3.2 Improving Appearance by Powder Coating of Aluminium

Another method used for improving the appearance of aluminium products is powder coating. This method is essentially a surface coating by pigment deposition of powder particles when the colour is obtained.

The method applied to paint aluminium does not differ from those generally used for all other metals. They include cleaning, brushing, spraying (manual or automatic). The more recent methods of powder coating are electrostatic processes.

For powder coating, a primary coat of zinc chromate is applied on aluminium to ensure good adhesion of the sprayed paint. A spray gun consists of a cup from which the paint is atomized and projected by means of a stream of compressed air in a spray booth. Then, it is taken to the furnaces and kept at suitable temperature for drying. Minimum thickness of 50 μm is essential for powder coating. A good finish of aluminium products can be obtained by either anodizing or by powder coating.

20.3.3 Comparison of Colouring Processes

Table 20.1 shows the comparison of colouring processes.

Table 20.1 Comparison between Electro Colouring and Powder Coating

Electro colouring (Anodizing)	Powder coating
1. Colour is attained by metal in deposition in pores of anodized layer; hence, it is highly durable	1. Colour is obtained by pigment coating
2. There is uniformity in colour in all parts	2. Inaccessible portions are difficult to colour
3. There is restricted range of colours	3. There is wide range of colours to choose from
4. No fading of colour takes place	4. Shades change under extreme temperature and corrosive conditions
5. It is non-peeling	5. There is danger of peeling, if work is not properly done or protected
6. No chipping occurs at fabrication stage	6. Chipping may occur, while cutting, drilling or when screw fastened

20.4 CHARACTERISTICS AND ADVANTAGES OF ALUMINIUM AS A CONSTRUCTION MATERIAL

The following are its important characteristics as a construction material:

1. ***High strength–weight ratio.*** This makes it advantageous to use for transportation—bus bodies, trucks, trains, aeroplanes, etc. Fuel savings are enormous. Aluminium is also preferred for orthopaedic implements like crutches.

2. ***High corrosion resistance.*** For high corrosion resistance to atmospheric agencies, aluminium is preferred to steel. This is an important factor for buildings near seashore and also for tall buildings. Aluminium marine alloys are used in boats and ships.
3. ***Safety against attack from insects.*** Most of the woods can be destroyed by white ants and borers, but aluminium is safe against them. So, aluminium is, often, preferred to wood for making door and window frames.
4. ***Economy in maintenance.*** It requires no painting and very little maintenance.
5. **Aesthetic appearance.** It has a pleasing appearance. It can also be anodized or powder coated to give various shades to match the surroundings.
6. ***Capacity to stand with low temperature (cryogenics).*** Aluminium is highly suitable for sub-zero temperatures, where structural steel becomes brittle and gives way. Aluminium is preferred for Antarctica expeditions. Its coefficient of expansion is 1.9 times that of steel, but as its modulus of elasticity is less, thermal stresses in it are less than that in steel.
7. ***Ease of fabrication and assembly.*** It can be cut, drilled or milled easily. It can be joined easily by bolting, riveting, welding, brazing or adhesive bonding. Extrusion technique provides unlimited opportunities of matching the design to specific requirements. It is easy to cut and assemble at site.
8. ***Air tightness.*** Aluminium extrusions can be made with very little tolerances, so that they can be fabricated with great precision. This is important for windows of high rise buildings, air-conditioned buildings and for several other uses.
9. ***Good noise control.*** Aluminium is good for noise control because of its excellent reflectivity of sound. It also reflects electromagnetic waves.
10. ***High scrap value.*** Unlike steel, the scrap value of aluminium is very high. When we rebuild a member it makes it cheaper in cost.
11. ***Ease of transport.*** Aluminium is easy to transport because of its light weight.
12. ***High reflectivity.*** Aluminium roofs absorb less radiant heat, as aluminium has good reflectivity. It is an ideal material for roofing and siding of workshop sheds. Aluminium paints and films are used for thermal insulation of roofs.
13. ***High conductivity of electricity.*** Aluminium wires are used for high voltage electric distribution. However, aluminium tends to oxidize in joints. Hence, joints need to be made carefully. It is preferable to weld wherever possible. Copper is a better material to be used in small sizes in house-wiring, as it is trouble-free.

20.5 AVAILABLE FORMS OF ALUMINIUM AND THEIR USES

Aluminium products are generally available in the following forms:

1. *Castings* (Automobile parts like cylinder blocks, cylinder heads, valve bodies and fittings. Rail coach seat fittings and marine fittings, storage tank fittings, pneumatic tools, large fan blades, electric motor and frames, chair base for office furniture, etc.)

2. *Sheets* (Utensils, roofing sheets, aircraft bodies, boats and ships)
3. *Foil* (For packing food, medicines, toiletries, etc.)
4. *Extrusions* (Doors, windows, ladder, transport vehicles, etc.)
5. *Wires* (For electric conductors mainly)
6. *Powder* (For paints, pyrotechnics, etc.)

20.6 ALUMINIUM ALLOYS

We have already seen that as pure aluminium is soft for different uses, it is alloyed with other metals to give the desired properties. These aluminium alloys are used for different works. There are many alloys developed by various manufacturers and institutions for cast products as well as wrought (made up) products. They can be divided into two groups.

1. ***Heat treatable alloys.*** These alloys give increased strength by thermal treatment.
2. ***Non-heat treatable alloys.*** The strength of these alloys is increased by work hardening, i.e., cold working.

The heat treatable alloys also respond to work hardening and are frequently cold worked after heat treatment to get higher strength. Annealing reduces the strength of all alloys, but enhances bending characteristics.

In day-to-day, we use cooking utensils containing pure aluminium containing about 0.4% iron and 0.25% silicon. Moreover, for manufacturing roofing sheets, we use aluminium with 1% to 1.5% manganese added as alloying element.

20.6.1 Important Alloys for Industrial Use

Three most important alloys of aluminium for industrial use, other than building construction, are duralumin, yalloy and aluminium bronze.

1. ***Duralumin.*** The chemical analysis of this high strength alloy (duralumin) is given below:

Aluminium (AI)	-	94%
Copper (Cu)	-	5%
Magnesium (Mg)	-	0.5%
Silicon (Si)	-	0.5%
Manganese (Mn)	-	0.5%
Iron (Fe)	-	0.5%

   Duralumin is used for manufacturing aircraft, automobile parts, etc. where strength, equivalent to that of steel, is required.

2. ***Yalloy.*** It contains 4% copper, 20% nickel and 1.5% magnesium. It is used for manufacture of pistons, cylinder head of IC engines, connecting rods and propeller blades.

3. ***Aluminium bronze.*** This alloy contains 78% to 90% copper with only 10% to 22% aluminium. It is used as a substitute for brass (which is an alloy of copper with tin, zinc or other base metal). Because of its anticorrosive nature in sea water, it is very much useful for marine condition. It is also used for grill work in buildings.

20.7 USES OF ALUMINIUM IN BUILDING CONSTRUCTION

Aluminium has many industrial uses as pointed out in Section 20.5. Use in buildings is a very small part of its usage. In this section, we deal with the use of aluminium in building construction. The four popular uses of aluminium products in building construction are as follows:

1. Window frame
2. Built up curtain walls
3. Aluminium composite panels (ACP) or wall panels
4. Roofing sheets

These are described below:

1. ***Window frames.*** As good wood is expensive and other woods do not last long in many modern houses, we use aluminium for window frames. A number of different slopes and colours can be made from aluminium alloys.
2. ***Built up curtain walls.*** Plain walls not supporting a roof are called *curtain walls*. In modern high rise buildings, brick, mortar and cement have been replaced by aluminium and aluminium composite panels, curtain walls. Nowadays, we get many types of glasses like float glass (toughened glass with high strength, which is shatterproof,) reflective glass (with attractive colour coating that reflects heat rays,) multilayered glass with attractive colour coating that reflects heat rays, multilayered glass with air gap to reduce heat conduction that saves electricity charges in air-conditioned rooms, etc.

   Built up curtain walls can be made with aluminium frames to which glasses can be fitted in conventional way. Development of silicone adhesive sealants, which give very strong bonds between aluminium and glass, has made "Structural Glazing" popular. Hence, the glass is pasted outside the aluminium frames, and as a result, very little of the aluminium frame is visible outside. Recently, "3M" Structural Glazing tapes are being introduced in place of sealants, which reduce the time of sealant application and the long curing time can be avoided.
3. ***Aluminium composite panels (ACP).*** These laminates have emerged as a very preferred material for facades, curtain walls. Face lifting of buildings for beauty can be achieved by using these composite panels. It is used in exteriors as well as interiors of buildings. The composite panel is shown in Figure 20.2. It is usually made 4 mm thick. It is composed of non-combustible low density polyethyline (LDPE) sheet laminated and sandwiched between two anodized aluminium sheets (0.3 mm) on each side and painted with special techniques. The upper sheet is coated with polyvinylidene and fluoride (PVDF) and the lower with polymer paints. Between aluminium and LDPE sheets, adhesive film compounds are applied. The resulting ACP sheet is lightweight

and has high peeling strength. It has high durability and weather resistance. It is fire resistant and has high anti-impact and anti-scratch properties. It has excellent sound and thermal insulation properties.

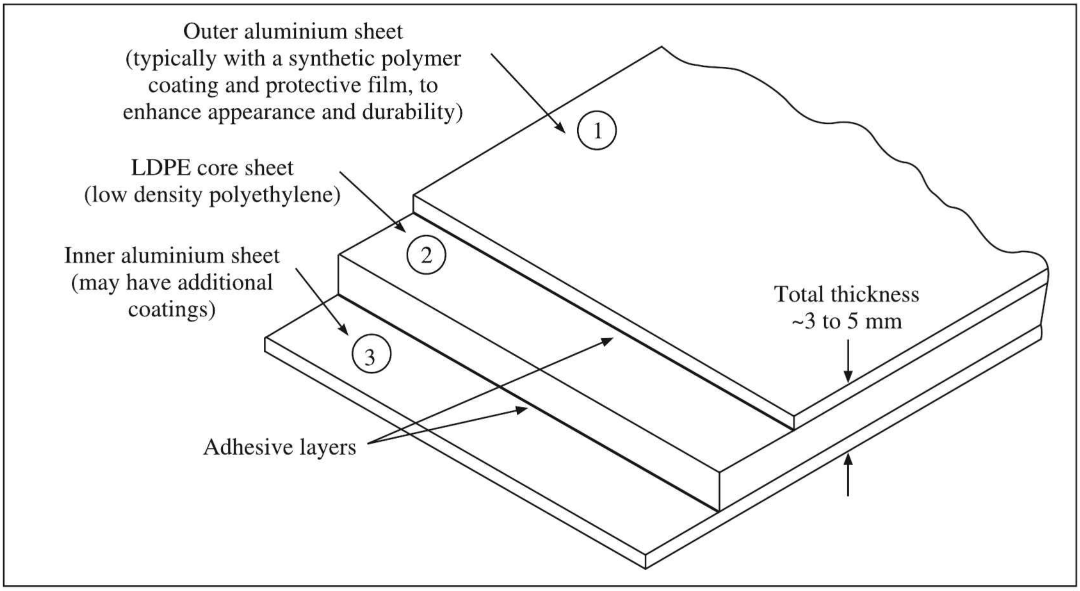


Figure 20.2 Structure of aluminium composite panels (ACP).

These sheets are used for facades of buildings to give attractive patterns. They can be easily bent to any shape to cover columns and pillars easily and it gives them very elegant look.

4. ***Aluminium roofing sheet.*** Roofing by rafters and clay tiles was very popular in olden days. It is becoming obsolete, as it involves a lot of labour. The tiles may also get broken in many ways. Nowadays, sheets made from high quality aluminium alloys, which do not rust, need little maintenance and look good for very long time, are available. These corrugated sheets are used for all classes of buildings, for industries, warehouses and even for housing. These corrugated aluminium sheeted building look attractive also. These sheets are available in a variety of colours. "Hindalco Everlast" roofing sheets are such sheets and are very popular nowadays.

SUMMARY

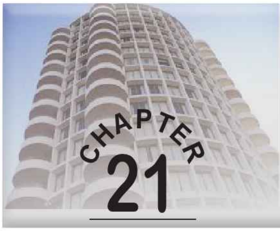
This chapter describes the manufacturing of aluminium as a metal, the methods of alloying it to give good properties and treating it to improve its appearance. It also describes the various uses of aluminium products in buildings.

REVIEW QUESTIONS

1. Describe the method of producing aluminium from bauxite ore.
2. What is the difference between anodizing (anodic coating) of aluminium and powder coating of aluminium? Where are their products used?
3. State why only aluminium alloys are used in industry instead of pure aluminium. Name three common alloys of aluminium and indicate where each of them is used.
4. State the advantages of using aluminium products in building construction. Briefly describe four items in building construction, where aluminium products are commonly used.

REFERENCE

[1] IS 1868–1996: *Anodic coating on Aluminium and its alloys.*



CHAPTER 21

Other Metals and Their Alloys

21.1 INTRODUCTION

In this chapter, we will consider some of the important metals and their alloys that are used in building construction.

21.2 COPPER AND ITS ALLOYS

Copper is extracted from ores like copper pyrites ($CuFeS_2$). The ore is first calcined in a reverberatory furnace and then smelted in a blast furnace. It is then oxidized in Bessemer converter to give blister copper which is then remelted and purified to get ordinary copper. Very pure copper can be obtained by electrolysis.

Copper is used in making electric cables and in places where we want resistance from corrosion. In ship-building industry, it is popular because of its resistance to seawater corrosion. In buildings, it can resist the action of atmospheric corrosion particularly in industrial centres and along the seacoast. Many old temples and important buildings are covered with copper roofs. *Copper is the most dependable material for house wiring.*

21.2.1 Alloys of Copper

The most important alloys of copper are brass and bronze.

1. ***Brass.*** Brass is an alloy of *copper and zinc*. It is stronger than copper and can be casted into moulds. There are many varieties of brass with varying amounts of copper and zinc. Brass fittings are very popular for doors and windows in places where corrosion can take place or for classical appearance. They can be made of cast brass and can be chromium-plated, copper- oxidized or nickel-plated for appearance. Plain brass fittings have to be polished frequently with polishing materials like Brasso to maintain its brightness.
2. ***Bronze.*** Bronze is an alloy of *copper and tin*. There are many types of bronze depending on percentage of copper. *Bell metal* (with 82% copper), *gun metal* (with 88% copper) and *phosphor bronze* (with 89% copper) are all alloys of copper. Gun metal bearings were very popular before ball bearings were introduced.

21.3 ZINC AND ITS ALLOYS

Zinc is extracted from its principal ore zinc blende (ZnS) by heating it in an electric furnace and condensing the zinc vapour to metallic zinc. Its important property is that it resists corrosion. In pure distilled water, zinc forms a loosely adherent film of hydroxide. This film dries in the presence of oxygen and carbon dioxide of the air to a film which is quite insoluble in rainwater. This affords protection from further attack. This is the property that makes it a good material for roofs and flashings. This is the reason why galvanized iron (GI) sheets are more lasting than plain steel sheets. However, sulphur gases in industrial atmosphere increases the possibility of destroying this film, thus making it a better material for rural atmosphere than for industrial atmosphere. We should remember that if zinc comes in contact with iron, copper or lead in the presence of moisture, then galvanic action starts and zinc is quickly destroyed. Hence, care should be taken in using these metabls together or side by side in any place.

21.3.1 Use of Zinc for Manufacturing of GI Sheets

Galvanizing of sheets like roof sheet is the process of coating iron or steel with zinc as a protection against corrosion. The products are called galvanized iron (GI) or galvanized steel sheets. The zinc coatings are desirable as zinc corrodes very much slower than steel. Also, at the cut edges, the zinc being anodic to the iron, gives galvanic protection until it is removed by galvanic corrosion. The life of zinc coating is directly proportional to the thickness of the coating. Roofing sheets are generally corrugated to give extra strength and are known as *Corrugated Galvanized Steel Roofing Sheets.*

For galvanized coatings, any of the following methods is used:

(a) *By hot dip process*—by dipping the article in molten size
(b) by electroplating
(c) by heating it in contact with zinc dust.

Most of the GI sheets are made by hot dip galvanizing. Tin is also added sometimes to the zinc bath only to give a bright sparking appearance to the sheet. In the hot dip process, the iron or steel sheet is first cleaned by “pickling” it in hot sulphuric acid. The iron salts are removed from the pickled material by rinsing and scrubbing. It is then dipped in 25% zinc chloride. After partial drying, the material is dipped in a molten bath of zinc. (Sometimes, dipping is carried out only after passing the sheet through a flux of zinc ammonium chloride.) The iron-zinc is formed on the surface of the steel with a few seconds. During the dipping, the longer the immersion, the thicker will be the layer.

21.4 OTHER METALS

There are many other metals used for various purposes in building construction. Of these, lead and nickel are the important ones. Brief description of these two metals is given below.

Lead. Lead is commonly extracted from its sulphite ore Galena (PbS). The ore is ground and impurities are separated by flotation. Coke and metallic iron are added to the ores and the mixture is smelted in a blast furnace. The impure lead obtained is purified in a reverberatory furnace. Lead is highly resistant to corrosion, hence it is used for making pipes carrying waste water (as wastepipe in washbasins) and in chemical equipments, etc. It is also used for making roof gutters, dampproof course, as lead oxide in paints, as well as for making bullets, storage cells, etc. However, it has been found that consumption of leads by humans leads to lead poisoning. Hence, the use of lead in water supply pipes, etc. is being forbidden in many countries.

Nickel. Nickel is extracted from its silicate and sulphide ores by first roasting the ore and then smelting it in a blast furnace along with limestone, quartz and coke. It is then treated in a Bessemer converter and purified by repeated smelting and electrolysis.

Because of its resistance to corrosion and appearance, nickel is mostly used as a coating to other metals. Monel metal is an alloy of 65 to 75 per cent nickel and copper and it is used for sheet metalwork of kitchens, restaurants and soda fountains. Being strong and tough, it is also used for valves, marine propeller shafting, springs, etc.

Nickel-silver or German silver is an alloy of copper, nickel and zinc.

Nickel-chromium alloy (nichrome) is an alloy with about 20 per cent chromium. It is used for resistance in heating devices likes electric heaters. It can be heated to very high temperatures (about 1050°C) without bad effects.

Nickel-copper alloys have 25 per cent nickel with copper. It is used for coinage because of its good appearance and toughness.

SUMMARY

Copper, zinc, lead and nickel are some of the metals other than steel and aluminium that are used in components related to building construction. Their alloys are also important.

REVIEW QUESTIONS

1. (a) Briefly describe how G.I. sheets are made. Explain how galvanizing acts as a protection to iron in G.I. sheets.

(b) What are the uses of copper in construction of buildings.

2. Briefly describe the tests used to test the zinc coating of G.I. sheets. (Refer Section 32.2.)

3. Wrie short notes on:

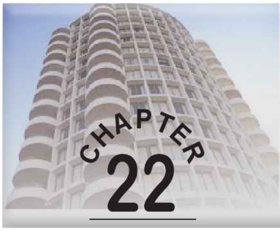
(a) Brass

(b) Bronze

(c) Gun metal

REFERENCE

[1] IS 2629–1985: *Recommended Practice for Hot-dip Galvanizing of Iron and Steel.*



Paints, Distempers and Varnishes

22.1 INTRODUCTION

Paints are coatings that are applied over metals, wood, plaster, concrete, etc. for *protection* against the elements and also to give a *good appearance*. They are usually built in layers as priming coat, first coat, second coat, etc. The commonly used paints in building construction are the following.

1. ***Oil paints*** or ***oil based paints*** are the earliest type of paints. They have a base, oil vehicle or binder and a thinner or solvent. It is described in Section 22.5.2.
2. ***Enamels*** (Enamel paints) are *solvent-based coatings* which are based on synthetic alkyl resins and have a higher level of gloss than ordinary paints. Enamel paints are generally used for metal and wood works. Enamels are described in Sections 22.5.3 and 22.5.4.
3. ***Emulsions*** (Emulsion paints) are *water-based coatings* used for walls with finishes ranging from mat to sheen. They are usually used in interiors because of the smooth finish they impart to surfaces. Textured emulsions are also used for the outside of buildings. Emulsions can be ordinary emulsions or plastic emulsions. Plastic acrylic emulsions are more expensive but give a better and washable finish to plastered walls. They are washable many times which is a unique feature of these paints. Emulsion paints are described in Section 22.5.5.
4. ***Distempers*** are *cheap water paints applied to plastered surfaces*. They are the lower grade of wall paints next to colour washing. They contain powdered chalk as base along with other binders. There are two classes of distempers—dry distemper and oil bound distemper (OBD) as explained in Section 22.6.
5. ***Cement paints*** are the paints which have white cement as its common base. These (paints) are described in Section 22.5.1.
6. ***Primers*** are range of coatings which are *painted on surfaces prior to the application of the final paint. Primers neutralize alkali effects of lime in cement.* All primers facilitate the adhesion of the subsequent coat of paints, enamels and emulsions. Different primers are used for different surfaces. Thus, for wood, steel and plastered areas, we use different primers. It is described in Section 22.7.
7. ***Varnishes*** are transparent or nearly transparent *solutions of resins* with thinner or oil. They usually do not have any pigment. They are applied to surfaces. After the thinner or oil evaporates, the remaining material dries to a hard transparent solid film either

by oxidation, polymerization or simple evaporation. The solid film protects, preserves and beautifies the surface. Lacquer is a varnish that solidifies by evaporation of the solvent contained in it rather than by one of the complicated processes of film formation. Varnishes are dealt with in Section 22.8.

In paint industry, there are two separate distinctive divisions—one that concentrates on *decorative paint industry* and the other concentrating on *industrial paint industry*. In India, at present, the decorative paint industry sector is larger than the industrial sector. In this chapter, we will restrict our study mostly to the products used in building construction which come under the category of decorative paints. In addition to decorating the surfaces, these paints also protect the components from deterioration of articles by atmospheric actions. Thus we have the following different fields in surface coatings.

(a) ***Decorative paints*** are the paints used for decoration of buildings and other type of surfaces.
(b) ***Industrial paints*** are the paints used for industrial products like automobiles, marine vessels. Industrial paints include corrosion-resistant paints, high-performance coatings and powder coatings.
(c) ***High-performance coatings*** are used in factories for plants, fertilizers, chemicals, nuclear energy, offshore installations, etc. where the metal needs protection from corrosion.
(d) ***Marine paints*** are the paints used in ships for anticorrosion and freedom from attack of marine organisms.
(e) ***Powder coating*** is a new technology used to coat consumer durables like refrigerators, washing machines, building equipments, etc. They can be used to give the desired colour on aluminium fittings.

22.2 PAINTS

The composition of paints is becoming more and more complex with advancement of paint technology and some of the modern paints can have from ten to twenty components, each component giving a specific quality to the paint. However, basically all paints consist of the following five components:

1. ***A base pigment.*** White lead, red lead, aluminium powder, etc. were the pigments that were used initially in oil paint. These materials form the bulk of the paint in a finely-divided state. It gives the durability and protection to the painted surface as they have high resistance to the elements. The base should suit the material to be protected. For example, white lead gives no protection to steel. It is used only for woodwork. Red lead base is used for steel.
2. ***A vehicle or binder.*** Materials like linseed oil when used as binder or medium, facilitate the spread of the paint and also bind the paint and the surface together. Binder can be oils, resins and bitumen or cellulose derivatives.
3. ***A solvent or thinner.*** It adjusts the viscosity of the paint to suit the method of application. Turpentine is generally used as a thinner in oil paints. In emulsion paints, water is used as a thinner.

4. ***A drier.*** It accelerates the process of drying of the paint. Substances like cobalt, lead, manganese dissolved in volatile liquids are used as driers.
5. ***Colouring pigments or extenders.*** They are added to give colouring and may also act as partially cheap substitute for the expensive base pigment.

22.3 CLASSIFICATION OF COMMON PAINTS

Paints can be classified in many ways. In building industry, paints are usually classified by one of the following ways:

(a) according to the nature of the binder,
(b) the way it dries to form the protective coating,
(c) according to its *use,* or
(d) according to its *main component.*

The following examples will illustrate the concept more clear:

1. Oil paints mean that the binder is oil.
2. Enamel paint simply means that it dries out as an enamel.
3. Anticorrosive paint denotes its use.
4. Bituminous paint denotes that the composition of the paint is bitumen.
5. Emulsion paint simply means that it is a water-based coating.

22.3.1 Pigment Volume Concentration Number

One of the terms commonly used to indicate the volume of the base pigment in a paint is PVCN, i.e. Pigment Volume Concentration Number.

$$\text{PVCN} = \frac{\text{Volume of base pigment in the paint}}{\text{Volume of non volatile vehicle in the paint}}$$

The value of PVCN depends on its use and the finish to be expected. Its common values are as follows:

25 to 40 for paints on metals
35 to 40 for paints on timber
28 to 40 for paints on exterior surface of buildings
35 to 40 for semi-gloss paint
50 to 75 for faint paint

22.4 CONSIDERATIONS IN CHOOSING PAINTS

There are many factors that should be considered while choosing a paint for a building. Some of them are the following:

1. *Nature of the surface to be painted.* Different types of paints are used for different surfaces like plaster, wood or metal. The paint should match the surface.

2. *Moisture in the material to be painted.* This is a very important consideration when we paint a plastered brick wall. A newly-built plastered brick wall has considerable moisture in it. The paint that is to be used on a moist wall should have the capacity to “breathe” which means it should allow moisture to pass through it. Cement paints which allow moisture to pass through can be used in this case. But with paints that form an impermeable film (as with oil paints or OBD), there will be bubbling and peeling off of the paint when moisture tries to get out of the wall. Such paints should not be used in masonry in damp conditions.
3. *Alkalinity of the surface.* The paint to be used on a lime plastered surface should be resistant to alkalies, otherwise it will react with lime. The paint will peel off such lime plastered surfaces. Such surfaces should be treated with a suitable *alkali-removing primer* before it is painted with some type of paints. The evolution of such primers has been a great improvement in paint industry.
4. *Relative humidity of atmosphere at time of painting.* Many paints do not stick to the surfaces when the relative humidity is high. Drying of paint will also be very slow. It will be better to postpone the work for drier days or use only the paints suitable under such conditions. Cement paints can be very well used when the humidity is high. Oil paint work should not be carried out during wet season.
5. *The purpose of using the paint.* Paint should serve the purpose it is meant for. If high decoration is needed, then decorative paint should be used. For protection of exterior of tall buildings, “exterior paints” that are antifungal and will last for a long time should be chosen as repainting tall buildings frequently is difficult and costly.
6. *Cost of the paint.* The paint should be affordable. Paints from very low cost to very high cost are available and the cost should suit the type of work. Low cost rural houses do not need very expensive paints that we may have to use for showeases of departmental stores. Whitewashing only may be sufficient for low cost buildings.
7. *The colour of the paint.* The colour should be stable for the environment it is to be used. Bright colours fade faster than light ones. Very bright colours should not be used for the exterior.

22.5 PAINTS COMMONLY USED IN BUILDINGS

The paints commonly used for buildings (decorating paints are different from industrial paints) are the following:

1. Cement paints
2. Oil paints
3. Ordinary enamel paints
4. Synthetic enamel paints
5. Plastic emulsion paints
6. Exterior paints
7. Lime washing and colour washing powders
8. “High build” paints

We will briefly examine each of them.

22.5.1 Cement Paints

These paints contain white cement, colouring pigments, accelerators and other additives ground together in fine powder. It is available in various colours. The surface to be applied should not be too smooth for its application. They can be applied on old or newly-built walls. It allows walls to breathe: Snoweem and Supercem come under this class. The powder form is mixed with water. Normal cement paints require curing of the painted surface. For exterior work, special waterproof cement paints are also available as exterior paint. However, recently, *cement paints that require no curing (called Unique)* are available in the market from Supercem company.

The advantages of cement paints are the following:

1. They can be applied on damp walls (where oil paints or OBD cannot be used).
2. Other paints can subsequently be painted on a surface painted with cement paint. Hence, in many cases, we use cement paint as the first paint for a new house and one or two years after the walls have dried, we use any other decorative paint for better appearance.
3. Painting with cement paint requires less skill.
4. Alkalinity of walls, due to use of lime, does not affect the paint. Walls once whitewashed with lime can be painted with cement paint after a delay of a few months, after the effects of lime has gone.
5. It is possible to give a fungicidal wash to walls before cement paints are used.
6. Redecorating walls of residences with ordinary cement paint is usually difficult as watercuring without affecting electrical circuits is difficult. *However, the newly-developed cement paints which need no curing can be used in such repainting works.*

The main disadvantages of cement paint are:

1. The walls have to be wetted by a brush before the cement paint is applied to give the paint a good bond.
2. Similarly, the walls should not be too smooth as otherwise the cement point will not adhere to the surface.
3. Most of cement paints require watercuring except the recently developed varieties. Watercuring inside rooms already occupied is difficult during repainting.
4. Cement paint should not be applied on surfaces which were painted by oil paints without removing the old paint.

22.5.2 Oil Paints

Oil-based paints are the classical type of paints with a suitable base and the vehicle, being oils of various types. They are cheap and easy to apply. However, if not applied skillfully, it can leave brushmarks after painting. They form a non-breathing membrane on drying and should not be used in damp situation. Painting work with this paint should not be carried out during damp weather. It can be used on all surfaces, especially *on indoor wood and metal works.*

22.5.3 Ordinary Enamel Paints

Ordinary enamel paints consist of mainly four components—metallic oxides (white lead, zinc white, etc.), oil, petroleum and natural resinous matter. Because of the presence of the resins, it dries to a hard glossy finish. It does not leave any brushmark on drying. They are available in glossy or matt finish. The painted surface is resistant to acids, alkalis and environment. *Enamel paints are mostly used for metal and wood works and also on concrete.*

22.5.4 Synthetic Enamel Paints

The medium for these paints are chemical compounds, one type being oil-modified alkyd resin. They have greater durability and corrosion resistance. These paints are available in market in various colours for and are very popular for painting metalwork (like grillwork) and woodwork in building construction.

22.5.5 Plastic Emulsion Paints

An emulsion is a liquid having fine suspended particles. One of the developments in decorative paint industry is the advent of these water-thinned emulsion paints. This paint contains vehicles (binders) of *synthetic resins*. Other constituents are pigments, other solids and water. Emulsion paints can be ordinary emulsion paints and plastic emulsion paints. In plastic emulsion paints, which are more popular, the emulsion is composed of plastic compounds such as vinyl acetate and acrylate, which are held in water. The film forming constituents of this paint is emulsified in water so that it can be thinned by water instead of solvents like turpentine used with oil paints. Emulsion paints are generally not used on metals as industrial paints but used only as decorative paints.

Oil paints dry slowly and need atmospheric oxygen to form films, which could be speeded up by driers to some extent. But coatings from emulsion paints develop their films by "conversion" through crosslinking in the presence of oxygen. The painted surface dries quickly and after drying, it can be washed with water. This type of paint is commonly used on brickworks and plastered surfaces. It is mostly used as an interior paint.

Emulsion paints are very popular because of their ease in application, quick drying property, good workability and no-objectionable odour. However, they are expensive and used only in high class buildings. As emulsion paints are widely used also because of their range of colours and decorative effects, we will examine their application a little more in detail.

1. Ordinary plastic emulsions are generally to be *used in the interiors and not exteriors* as its resistance to external effects is low. For exterior, special exterior paints should be used.
2. This paint is thinned by water and hence, unsuitable for metals. It is mainly used for plastered walls in buildings.
3. The success of painting with plastic emulsion paint depends on the preparation of the base. As the paint can adhere to even a *smooth surface, a smooth finished surface is preferred for this paint. Surfaces should be prepared carefully with putty or other means*.
4. Even though it is claimed that this paint allows the walls to breathe (allow moisture to escape through minute pores), it is desirable to apply it only on dry walls and not on damp walls that have just been built.
5. The paint can be applied by brushes or rollers.

6. The paint should be applied as thin coats not more than 0.04 mm. Usually, two coats are applied. The second one is applied after the drying of the first one.
7. *The paint is to be thinned by adding potable water* generally 1/2 litre per kg of paint for first coat and 1/4 litre per kg for the second coat (first coat is generally made thinner).
8. For dark colours, the paint as prepared by the manufacturer with no mixing should be used. For light colours, the white emulsion paint can be mixed with special tainters supplied by the manufacturer.
9. The walls painted with plastic Emulsion can be maintained easily by moping the soiled parts with a wet cloth.

22.5.6 Exterior Paints

With the construction of a large number of multistoreyed buildings with exposed surfaces in Indian cities, a demand has been created for special paint for coating the exterior of tall buildings. These exterior paints should have, in addition to good appearance, the ability to withstand fungus, moss, etc. that can accumulate on outside walls. They should also be *waterproof and long-lasting as painting multistoreyed buildings often is not easy.* These paints are expensive and most of them are acrylic paints. Paints ranging in cost from a few rupees to hundreds of rupees per sq metre are available in the market and one must choose the paint with care. They are used for external brickwork, plasterwork, etc. Special waterproof cement for exterior use is also available, which are comparatively cheap.

Exterior paint industry is a subset of decorative paint industry. All the Indian paint companies have their own brand of antifungal, antialgae, exterior emulsion paints which are widely advertised. Before using the paint, filling in crevices, plastering damaged places, etc. should be carried out carefully for the painting to be effective. Bright colours for the exterior should be avoided because of their heat absorption and likelihood of fading sooner than light coloured paints. Some of these paints are claimed to be reflective paints reducing heat absorption of buildings. Acrylic exterior paints, even though costly, have proved to be very effective in protecting exteriors of multistorey buildings.

22.5.7 Whitewash and Colourwash

Whitewash is prepared from fat lime obtained from pure shelllime or pure stonelime. Colour washing materials are essentially pure lime to which pigments are added to give the desired colour and both of them are ground together. This type of painting is very cheap and forms the bulk of painting in low cost houses in rural areas in India. Generally, painting works with these paints need three coats to get a good looking surface.

22.5.8 High Build Paint Coatings

High build paint coatings are generally used on interiors to give the effect of glazed brick. Some coatings are based on two components—urethane polyesters and epoxies. Others are an emulsion-based coat with acrylic lacquer. These paint systems usually include fillers to smooth out surface irregularities.

22.6 DISTEMPERS

Distempers are very much used in buildings. Distempers are water paints consisting of whiting (powdered chalk) as the base with glue, resin or acrylic (synthetic) as the binder and water as the carrier or thinner. Colouring pigments are also added to give the various shades. They are comparatively cheap, durable and can easily be applied. They are commonly used for interior works of buildings on plastered surfaces, wall boards, etc. They are more durable and decorative in appearance than whitewash or colourwash. Distempers are available in two forms namely ordinary (soft) distemper as dry distemper and oil-bound distemper (OBD).

The dry distemper comes in powder form. It shall be stirred slowly in potable warm water as specified (usually at 0.6 litre of warm water per kg of distemper). It is allowed to stand for at least 30 minutes before use. The mixture is then stirred well and used. Distempers are classified as only a little more durable than colourwash.

Oil-bound distempers (OBD) are a variety of oil paints in which the drying oil is so treated that it mixes with water. Hence, such paints can be thinned with water for painting. They form a durable and washable surface on drying. As it is oil-based like oil paints, it should not be used in damp situations. Finished OBD surfaces are washable. *Oil-bound distemper is marketed as a thick paste having the consistency of soft butter.* Water is to be added slowly while stirring to obtain a brushable mixture (usually 0.6 litre per kg of paste). The amount of water to be added depends on the texture and porosity of the wall surface.

22.7 PAINT PRIMERS

Before the desired paint is painted on a new surface, a first coat called *priming coat* is usually applied to the surface to be painted. This priming coat material is called *a primer.* Separate primers are used for different surfaces like wood, metal, plaster and also for different types of paints. The purpose of the primer is to fill the minute pores of surface to be painted and present a smooth surface for the subsequent application of paints. In walls, an alkali-resistant primer is usually applied to neutralize the effect of alkalis present (due to lime) on them before costly paints like plastic emulsion paints are applied. For old walls, a diluted mix of plastic emulsion paint used as the first coat can be used as the primer coat.

The ready made "cement primer" is an alkali-resistant primer applied on newly-plastered walls, concrete or brickwork. It has good sealing properties and good resistance to wall-alkalinity, moisture and fungus. Separate primers known as wood primers and steel primers are available for wood and steel.

22.8 VARNISHES

As already pointed out, a varnish is a solution of resins or resinous substances prepared either in alcohol or turpentine. It contains the following ingredients (Section 22.1):

1. Resins or resinous substances like shellac, resin, lac, etc.
2. Solvents like methylated spirit, wood naphtha.
3. Driers which accelerate drying. Litharge, white copper and lead acetate can be used as driers.

22.8.1 Type of Varnishes

Depending on the solvent used, there are four *categories of varnishes:*

1. *Oil varnishes*: Amber, copal in linseed oil
2. *Spirit varnishes*: Lac, shellac, etc. in methylated spirit
3. *Turpentine varnish*: Rosin, Gum dammar, mastic in turpentine
4. *Water varnish*: Shellac in hot water (with borax, potash or soda added) to dissolve the shellac

Varnish is usually applied to wood and the process is called varnishing. Special brushes (fine haired), called varnishing brushes and not the ordinary paint brushes are used for varnishing. It can also be done with a polishing pad of absorbent (woolen cloth) covered by a fine cloth. Varnish is applied in several coats till a very polished surface is obtained.

There are many types of varnishes with *different names*. Some of them are as follows:

1. ***French polish.*** The high class spirit varnish made by dissolving black or light brown shellac at the rate of 0.15 kg of shellac in one litre of methylated spirit without heating is called French polish.
2. ***Lacquer.*** It is identical with French polish, colouring pigments depending on the colour wanted are also added to form lacquers of different shades.
3. ***Copal varnish.*** Varnish made with copal in boiled linseed oil is known as copal varnish.
4. ***Furniture polish.*** This is a special preparation for furniture. It is made up of linseed oil, methylated spirit, copal varnish and other ingredients. It is also available as ready-made product in the market.
5. ***Stains.*** Stains are liquid preparations applied to cheaper light coloured wood to make it look like wood of superior quality.

22.9 SHORT DESCRIPTION OF PAINTWORKS IN BUILDINGS

The following is short description of some of the paintworks, far buildings:

1. ***For repainting walls.*** Providing two coats of *Supercem Cement Paint* for walls after cleaning the existing surface with water and curing the surface after painting (or painting the surface with suitable cement paint that does not require curing).
2. ***For repainting ceiling.*** Cleaning the surface and providing two coats of approved *acrylic distemper* (OBD) for interior ceiling.
3. ***For repainting interior walls.*** (a) Cleaning the wall surface and applying putty and primer whereever required and providing two coats of approved *synthetic enamel paint,* (b) Preparing the new surface and applying one coat of water-based cement primer and one coat of full putty with two coats of approved *acrylic emulsion paint* on internal walls.
4. ***Repainting of doors and windows.*** Cleaning the surface and applying two coats of approved *synthetic enamel* paint for doors and windows.

5. ***Repainting steel grillwork.*** Cleaning the surface and applying two coats of approved *synthetic enamel* paint for all steel grillworks.
6. ***Repainting external walls.*** Cleaning the existing surface and filling-in of cracks and crevices with appropriate filler, wirebrushing all fungal and algae and providing two coats of *antifungal exterior emulsion paint* of approved make and colour.

22.10 INDUSTRIAL PAINTS

Industrial painting is a separate subject. In addition to conventional type of paints, a number of innovations have been developed in industrial painting for special purposes.

22.10.1 Conventional Type Industrial Paints

The following are some of the conventional type of industrial paints:

1. ***Aluminium paints.*** In this paint, finely-ground aluminium is suspended in quick-drying spirit varnish or slow-drying oil varnish. They are used to paint gas tanks, hot water pipes, radiators, etc.
2. ***Anticorrosive paints.*** They are of various types like anticorrosive bitumen paint used for cast iron and red oxide or zinc chlorate paints used for steelwork. The latter type is very much in use.
3. ***Synthetic rubber paints.*** Synthetic rubber and chlorinated rubber paints are used as protective paints.
4. ***Epoxy paints.*** These paints are special formulations for waterproofing and protection from environment.
5. ***Cellulose paints.*** These paints are mainly used as spray paint in car industry. They may also be used for furniture and fittings in houses.

22.10.2 Some Advances in Industrial Paint Industry

We have already seen that in the decorative paint industry, the first development was the replacement of old oil paints by the water-thinned emulsion paints. Similarly, many advancements have also been made in the industrial sector as well. One such advancement in industrial painting sector is *electrocoating* in which the metal object to be coated is made the anode of an electrical circuit and immersed in a bath of paint. The process is similar to electroplating. Another development is *powdercoating*. The paint is in powder form and is based on resins of types similar to those used in solvent-thinned paints but have been designed so that the final film can be formed by melting of the paint which has first been deposited on the surface as a powder. Nowadays, thermosetting resins as powder are applied by electrostatic spray gun and these are melted rapidly on further heating. Such coatings require thorough preparation of the surface and high technology which is possible only under factory conditions. By powdercoating of aluminium, we can make it look like wood to be used for doors and windows in buildings to give it a conventional look.

22.11 COVERING CAPACITY OF PAINTS

The covering capacity of a paint can be defined as the area in square metres that can be covered by one litre of paint when the paint is sold in liquid form or one kg of paint when it is sold in powder form as one coat. It should be noted that for new buildings, the coverage will be less, and when applied as a second coat or applied on old walls with the same colour, the coverage will be more. The approximate coverages of different paints are given in Table 22.1.

Table 22.1 Approximate Covering Capacity of Paints

S.No.	Material used	Covering capacity on new surfaces per coat
	A. Decorative paints	
1.	*Wall-neutralizing cement primer.* It is a high-grade primer on cement plaster and concrete surfaces. It has good resistance to dampness. Also used on new or old A.C. sheets before painting.	12 to 14 m2/L
2.	*Synthetic OBD.* It is like *butter* and can be thinned with up to 80% of water for first coat.	10–12 m2/L
3.	*Ordinary distemper (colour powder).* It is an inexpensive paint for interior.	17 to 22 m2/kg
4.	*Superior acrylic plastic emulsion paint.* It is suitable for interior and exterior, can be thinned to 100% with water and easily spreadable over cement and wood primers. It is washable.	22 to 25 m2/L
5.	*Inexpensive emulsion paint.* It is fit for interior only	18 to 20 m2/L
6.	*Cement paint like Snowcem.* It is suitable for interior and exterior brickwork, concrete plaster, pebble dash, concrete block, etc. These paints need curing.	2 to 4 m2/kg
	B. Exterior paints	
1.	Acrylic plastic emulsion (exterior paints)	5.5 to 6 m2/L for 2 coats
2.	Cement paint (ordinary)	2 to 4 m2 per kg (one coat)
3.	Cement paint (Trade name "Unique" sold by Supercem which does not need curing.)	(+20% *cement paint*)
	C. Metal and wood paints	
1.	*Synthetic enamel paint.* To be painted on primer. (Red oxide zinc chromate primer for metal and wood primer for wood)	
	(a) Superior	18/22 m2/L
	(b) Ordinary grade	15/22 m2/L
2.	*Steel primer.* Red oxide or zinc chromate primer	14/18 m2/L
3.	*Wood primer.* Pink primer for wood	14/18 m2/L
4.	*Aluminium paint.* For storage tanks, pipes roof girders and trusses. Can be applied on respective primers on steel and wood.	20/22 m2/L
	D. Preservatives and varnishes	
1.	*Wood preservative.* (Brown and clear). Suitable for interior and exterior.	14/16 m2/L
2.	*Capal varnish.* General purpose varnish	14/16 m2/L
3.	*French polish.* Suitable for wooden furniture	14/16 m2/L
4.	*Melmanised finishes.* Brushing	8–10 m2/L
	Spraying	5–6 m2/L
5.	*Polyurethane clear wood finish.* Brushing	8–10 m2/L
6.	*Wood sealer paint.* Brushing	8–10 m2/L

SUMMARY

Finishing work on masonry, wood and metal is an important item in building construction. The final appearance of the building is very much influenced by the finishing works of a building. There are a large number of commercial and indigenous products that are used for this purpose. Paints, distempers and varnishes dealt with in this chapter are important building materials used for these finishing works. The details of the methods of painting different surfaces are also important and will be dealt with under building construction.

REVIEW QUESTIONS

1. Write short notes on:
   (a) Paints
   (b) Distempers
   (c) Varnishes
   (d) Highbuild paints
2. Explain what is the difference between decorative paint industry and industrial paint industry.
3. What are the different types of paints used in building construction.
4. What materials would you use for painting the following works. Give reasons for your preference.
   (a) New brickwork plastered with cement plaster
   (b) Old brickwork plastered with lime plaster
   (c) Wooden doors and windows
   (d) Steel grillwork in a building
   (e) Outside wall surfaces of an old multistoreyed building
5. What are the constituents of oil paints? On what surfaces will you use them? What are the precautions you would take in using oil paints?
6. What are plastic emulsion paints and where are they used in building construction? How do you mix the commercial product at the site for paintwork?
7. What are distempers? In what form they are commercially available? How do you prepare the commercial product in the field for painting?
8. What are varnishes? Explain their use in the building industry?
9. What are exterior paints? Explain their use in buildings?
10. Explain the terms (a) Electrocoating (b) Powdercoating used as industrial paint?
11. What are primers and in what situations do you use them?
12. Write short notes on:
    (a) PVCN
    (b) French polish

(c) Powdercoating
(d) Plastic emulsion paint
(e) Enamel paints
(f) Distempers
(g) Colourwashing
(h) Anticorrosive paints for steel work
(i) Covering capacity of paints

13. Give reasons for the following:
(a) Care should be taken in choosing a suitable paint for a newly-plastered wall.
(b) An oil paint should not be applied during humid weather.
(c) For painting of exterior of multistoreyed buildings, a different type of paint than that used for interiors should be selected.
(d) Plastic emulsion paints are not suitable for metals.
(e) For application of cement paints, the surface should not be very smooth.
(f) An oil paint with white lead as base is not suitable for steel but only for wood.
(g) If curing of inside walls in a residence with ordinary cement paint is difficult, then one has to use special types of cement paint.
(h) Ordinary plastic emulsion paints are generally used for interior work.

REFERENCES

[1] IS 6278–1971: *Code of Practice for Whitewashing and Colourwashing.*

[2] IS 5410–1992: *Cement Paint—Specification.*

[3] IS 427–1965: *Specification for Distemper Dry, Colour as Required.*

[4] IS 428–2000: *Washable Distemher—Specification.*

[5] IS 109–1968: *Specification for Ready Mixed Paint, Finishing, Priming, Plaster to Indian Standard Colour No. 361, 631 White and Offwhite.*

[6] IS 15489–2004: *Paint Plastic Emulsion—Specification.*

[7] IS 133–2004: *Enamel, Interior (a) Undercoating (b) Finishing—Specification.*

[8] IS 347–1975: *Varnish, Shellac for General Purpose—Specification.*

[9] IS 348–1968: *Specification for French Polish.*

[10] IS 524–1983: *Varnish-finishing Exterior, Synthetic Air-drying—Specification.*

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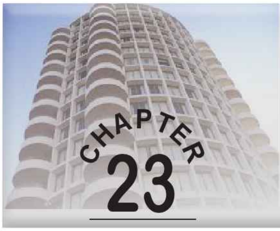

CHAPTER 23 Rubber

23.1 INTRODUCTION

Rubber is also known as an *elastomer*, (elastic in its behaviour under load and is different from *plastomer* which behave plastic under load). It is produced as a natural product from rubber trees and also manufactured by chemical processes. The former is known as natural rubber and the latter as synthetic rubber. Natural rubber has high strength, low hysteresis and good resistance to tear as well as flexure. However, it is easily get affected by solvents. Synthetic rubber can be produced to serve different purposes like chemical resistance. Usually synthetic rubber is mixed with natural rubber to produce different articles of rubber. Rubber is also produced as "reclaimed rubber" by reclaiming it from used wornout articles like automobile tyres. Reclaimed rubber is mainly used for making unimportant items like hosepipes, and other equipments, etc.

23.2 NATURAL RUBBER

The milk from rubber trees called "*latex*" is collected at rubber plantations. After removing the impurities, it is coagulated by weak acetic acid. The solid matter is passed through rollers to get *creep rubber*. In this form, it is marketed by the producer. This creep rubber is then processed to get commercial rubber compounds. The latex can also be preserved without coagulation by additives. In this latex form, it is used for many purposes like paints, foamed rubber mattresses, rubber gloves, etc.

23.3 SYNTHETIC (POLYMER) RUBBER

Rubber is a polymer (See Chapter 24). The developments in synthetic rubber started after World War II (around 1945) when natural rubber was in short supply. At present, we get, generally speaking, two types of synthetic rubber.

1. *General purpose synthetic rubber*. The most important of which is SBR (Styrene Butadiene Rubber).
2. *Special purpose synthetic rubber* with special qualities to suit different purposes. Neoprene is a synthetic rubber used for bearings for bridges.

23.4 VULCANIZATION OF RUBBER

We vulcanize rubber to improve the qualities of rubber to resistance to friction, solvents, durability, etc. and to make it stable at all temperatures. Rubber is vulcanized with sulphur. With addition of 1 to 5 per cent of sulphur, we get soft rubber and when we add about 30 per cent of sulphur, we get a very hard variety. Compounding of rubber is a specialized art and science kept as a close secret by many rubber companies. For making rubber tyres, fillers like carbon black are also added to improve their rigidity. They are also reinforced with nylon threads or steel wires to make them stand up to heavy impact loads and shocks.

23.5 USES OF RUBBER IN BUILDING CONSTRUCTION

Rubber is a very important industrial product. The following are the uses of rubber in building construction:

1. Rubber is used in cement mortar (polymer mortar) to improve its bonding and waterproofing qualities.
2. Rubber is directly used in concrete for making polymer concrete.
3. Rubber tiles for rubber floors (resilient floors) are made from natural or synthetic rubber as the basic ingredient.
4. Natural and synthetic rubber is used indirectly to make many products used in building industry. Thus, plasticized PVC pipes are made by addition of rubber (See Chapter 24). In many glues like Fevicol, rubber is added for superior adhesion.
5. Neoprene (a synthetic rubber) is extensively used for bearings of bridges.

23.6 RUBBER IN CEMENT MORTAR AND CONCRETE

We have already discussed in Section 10.7 how SBR is used in cement mortar. Latex or polymer latex incorporated in cement mortar forms a polymer-modified system which exhibits (a) excellent adhesion, (b) improved tensile, compressive and flexural strengths, (c) excellent resistance to penetration of water and (d) improved resistance to chemicals. Addition of natural latex is also partially successful but is not as good as synthetic products. This property can be used in preparing bonding agents. We add these rubber bonding agents to cement which is used for repairing concrete and plastered surfaces. It can also be used for making polymer concrete for waterproofing. During the process of hydration of cement along with the polymerization of latex-based polymers, the pores in the cement mortar or concrete get coated with the latex film. Formation of this latex film in the pores gives it good waterproofing qualities by preventing capillary rise of water. As synthetic rubber formulations are costly, this mortar is used only in special situations. Rubber can also be used for making polymer concrete (Refer Sections 10.7 and 12.7).

23.7 RUBBER FLOORS

In some situations like computer rooms or libraries, we need *resilient floors.* These floors are noise proof and have the ability to be compressed and come back to original shape when the load is removed. Rubber tiles laid on any rigid floor can be used for these resilient floors. Tiles are produced in plain colours or mottled to form a resilient, non-slip, quiet flooring of low thermal and electric conductivity. Linoleum and PVC are other materials also used for resilient floors. (See Section 31.5)

SUMMARY

Both natural and synthetic rubber are used for various purposes in the building industry. Its uses as an adhesive in many situations and its use as a bonding and waterproofing agent in cement plaster as well as in cement concrete are becoming prevalent in building construction.

REVIEW QUESTIONS

1. Explain vulcanization of rubber.
2. Briefly state the use of rubber in building construction and bridge construction.
3. Distinguish between natural rubber and synthetic rubber.
4. What are resilient floors? What materials are used for such floors? Where do you recommend the use of such floors?
5. Explain the use of latex and polymer latex as a bonding agent for plasters and polymer concrete. How does addition of polymer to cement make it waterproof?

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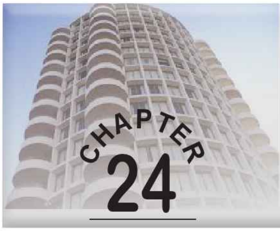
[1] IS 809–1992: *Rubber Flooring Materials for General Purposes—Specification.*

[2] IS 1197–1970: *Code of Practice for Laying Rubber Floors.*



CHAPTER 24 Plastics

24.1 INTRODUCTION

All plastics are polymers of carbon compounds. They are compounds of carbon with other elements like hydrogen, oxygen, nitrogen, etc. They are called plastics because their resins are capable of plastic deformation when heat and pressure are applied on them. Their molecular structure consists of long chains of large molecules loosely tangled together. A metal like steel has small molecules tightly packed. This causes plastics to have light weight and lack of stiffness. It has toughness and good tensile strength. A large number of plastics can be manufactured by changing the composition, length and character of their chains. There are more than 10,000 varieties of plastics today and their number is increasing everyday as new ones are being invented. In this chapter, we will study their general nature and a few of the important plastics we frequently come across in our daily life and building industry.

24.2 SHORT HISTORY OF PLASTICS

The first plastic was invented by Alexander Perkes in 1865 was called Parkesite. It was produced by mixing camphor and alcohol with nitrocellulose. Thereafter, Bakelite was discovered in 1909 by Bakeland. Later, Pollak prepared a plastic from urea and formaldehyde (amino plastics) which was transparent like glass and unbreakable (Section 24.7.7). Many industrial houses like ICI started research on production of plastics and today we have many special plastics. They are used for all purposes from making wearing fabrics to gears for machines. They are also used in paints, laminates and bathroom fittings. Most materials of modern life are someway connected with plastics.

24.3 POLYMERIZATION OF PLASTICS

The process of producing resins of plastics is called polymerization. A substance containing one primary chemical is a *monomer*. Combining thousands of monomers as a long chain of molecules is called *polymerization*. Thus, polymerization is the process of combining molecules of compounds to form another complex molecule. It can be represented as follows. If A is a monomer and if we combine n number of monomers to make a new compound, then the process is polymerization.

$$nA = A_n$$

The product is called a polymer. Natural rubber is a polymer (a wonder product) made by nature itself in rubber plants with the help of sunlight, in nature's chemical laboratory. Polymerization can be brought about by chemical methods in industry by the following three ways:

1. ***By addition polymerization.*** In this process, the *same molecules* are made to form a bigger molecule. Thus, in the preparation of polythene (polyethene), ethane, a carbon compound, is passed under pressure into an inert solvent containing a special catalyst (a Ziegler catalyst named after the inventor of the process) to form the polymer. A high density form of ethane called *polyethane or polythene* with a softening point of 130°C is produced. (We are familiar with polythene sheets in our everyday life.)

   $$3n(CH_2 + CH_2) \rightarrow (-CH_2 - CH_2 - CH_2 - CH_2 - CH_2 - CH_2 -)_n$$

   The reaction can be represented by the above equation where the value of n is about 300. Thus, polythene is an *addition polymer.* Polyvinyl chloride is another addition polymer.
2. ***By condensation polymerization.*** In this process, a *large number of identical or different molecules* combine and a low molecular substance is removed. For example, terylene is a condensation polymer. It is synthesized from alcohol, ethane, glycol and a benzene derivative when heated together, eliminates molecules of water between them and become terylene. Nylon is another example of a condensation polymer.
3. ***Co-polymerization.*** In this process, two or more *different monomers* are added together to form a polymer. Phenol formaldehyde is produced by reaction of phenol and formaldehyde.

Many of these products are produced in the form of resins and as described in Section 24.6, they are made into articles and also used for paints, etc.

24.4 CLASSIFICATION OF PLASTICS

Plastic can be classified according to its thermal property or mechanical property. According to thermal property, plastics can be classified into the two following groups:

1. ***Thermoplastics*** are plastics which soften on heating without undergoing any chemical change. It is, thus, possible to shape and reshape these plastics by heat and pressure.
2. ***Thermosetting plastics*** (thermosets) undergo a chemical change when heated at about 127–177°C and a new inert material which does not soften on subsequent heating is formed. Only charring occurs when heated to higher temperatures (at about 340°C) which is a peculiar feature of this type of plastics. Another distinguishing feature of thermosetting plastic is that when a corner is with a knife, chips of smaller pieces are formed, rather than splinters (shivers).

The following two terms are also of interest while dealing with plastics.

(a) ***Thermoplastic elastomers (TPE).*** These are elastic and rubbery compounds at normal temperatures.

(b) ***Gel.*** These are dilute polymer solutions which form into soft solids called gels. Such fluids can be pumped and form in-situ gels, those injected into soils to help soil consolidation.

Table 24.1 gives a list of the major thermoplastic and thermosetting plastic materials, their characteristics and typical applications.

Table 24.1 Plastic Materials

S.No	Material	Characteristics	Uses
		A. Thermoplastic family (they melt when heated)	
1.	Polyethylene (or polythene) low density	Flexible, feels like paraffin wax	Bottles, buckets, sheeting water tanks
2.	Polyethylene (or polythene) high density	Stiff and hard and coarser than the polyethylene of low density	Large storage bottles, water tanks
3.	Polypropylene	Smooth, rigid, lightest of all plastics (floats in water)	W.C. cisterns, sink traps, washing machine bids
4.	Acrylic	Glass clear, somewhat brittle sound when tapped.	Glazing, baths and sinks
5.	PVC	Rigid, tough, elastic to feel	Pipes, corrugated roofing sheets, plastic coating to steel sheets tanks, water cisterns
6.	Polystyrene	Solid, glass clear and sparkling	Refrigerator containers, food trays, packaging
7.	Nylon	High density polythene but smoother to feel	Textiles, brush bristles, carpeting, surgical trays, bearings, pressure tubing
		B. Thermosetting family (thermosets)	
1.	Melamine Formaldehyde (formica)	Hardest of common plastics, heat resistant	Electric insulators decorative laminates, table ware, glass fibre reinforced plastics
2.	Phenolics (bakelite)	Heavy solid plastics material, fishy smell when burnt dark in colour. The cheapest. Heat resistant, has weathers well	Bottle caps, plastic automobile parts, bonding plywood and chip board, glues, laminates with other materials
3.	Urea formaldehyde	Similar to phenolic but can be produced in lighter colours	Door furniture, light switches and electrical fittings, glues, bottoms, radio cabinet
4.	Epoxies	Resin and hardener	Used as adhesives
5.	Polyesters	Produced as fibres and films	Used for reinforced plastics

24.4.1 Classification According to Mechanical Property

According to the mechanical property, plastics are divided as follows:

1. Rigid plastics with high modulus of elasticity
2. Semi-rigid plastics with medium modulus of elasticity

3. Soft plastics with low modulus of elasticity
4. Elastomers which can extend to as much as ten times its original length. (act like rubber)

24.5 PROPERTIES OF PLASTICS

The main desirable properties of plastics are the following:

1. *Appearance.* It can be made in attractive colours.
2. *Chemical resistance.* It has good resistance against almost all chemicals.
3. *Dimensional stability.* It has good dimensional stability as with other engineering materials.
4. *Durability.* Many plastics are quite durable if protected.
5. *Electric insulation.* They are good insulators and hence, extensively used for plugs, switches, etc.
6. *Easiness in fixing.* They are easy to be used for fabrication.
7. *Finishing.* It can take good finishes.
8. *Light in weight.* Because of their molecular structure, plastics are light.
9. *Maintenance.* They are easy to maintain.
10. *Thermal conductivity.* It is very low like wood.
11. *Thermal stability.* It is stable under low temperatures.

The main undesirable properties of plastics are as follows:

1. *High thermal expansion.* It is about ten times as much as steel.
2. *High creep properties.* Plastics exhibit high creep.
3. *Lack of durability.* Under direct sunlight, they are not durable.
4. *Lack of ductility.* Most of the plastics have low ductility.
5. *Lack of fire resistance.* All plastics cannot withstand high temperatures. They may also emit toxic fumes in case of fire in buildings.
6. *Low melting point.* Thermosetting plastics are less affected by heat and burn at high temperatures. Thermoplastics melt at lower temperatures.
7. *Non-suitability for structural members.* Plastics has not yet become a popular material for fabrication of structures. For structural use, they are usually used only with embedded metals like steel.

24.6 FABRICATION OF PLASTIC ARTICLES

The raw materials for plastics come in the form *of resins*, which are in solid form. Plastic articles are made from these plastic resins. For this process, certain moulding compounds are added to the resins. Then, they are processed for fabrication into different articles.

24.6.1 Moulding Compounds

To give the desired properties to the finished plastic articles, the following moulding compounds are usually added:

1. *Catalysts* to assist and accelerate hardening of the resin.
2. *Fillers*, fibrous, laminated or powder fillers are inert materials added to give body to the plastics.
3. *Hardeners* to increase the hardness of the resin.
4. *Lubricants* applied to the surface of moulds for easy release of the article.
5. *Pigments* added for colour.
6. *Plasticizers* for improving plasticity and imparting softness to the plastics.
7. *Solvents* to dissolve the plasticizer.

24.6.2 Fabrication Methods Used for Making Plastic Articles

The following are some of the processes used to fabricate different types of articles of plastics:

1. *Blowing*. It is used in glass industry to produce many products.
2. *Calendaring*. It is carried out by passing through a set of rollers for producing plastic films and sheets.
3. *Casting*. It is used as in metal casting.
4. *Laminating*. It is applied in production of laminates of thermosetting plastics that are applied on paper, glass, fibre, etc. and pressed to get laminates. (Section 16.6.1)
5. *Moulding*. It is the most commonly applied method. It can be done in one of the following ways:
   (a) *Compression moulding*. In this method, plastic materials are placed in the mould, closed, and heated under pressure when the plastic materials are shaped in the mould.
   (b) *Extrusion moulding*. In this process, the raw materials are fed in machines and heated when they become plastic. It is then pressed through a die (i.e. extruded) to take the desired form. This is a continuous process used for thermoplastics.
   (c) *Injection moulding*. In this process, the heated plastic materials are injected into moulds at room temperature where they take the form of the articles to be made. This is applicable to thermoplastics.
   (d) *Transfer moulding*. This is applicable to thermosetting plastics. In this process, the moulds used are heated moulds.
   (e) *Jet moulding*. This process is like extrusion moulding except that for higher temperatures, the nozzles are also heated. This process can be used for both thermoplastics and thermosetting plastics.

24.7 SOME PLASTICS IN COMMON USE

In this section, we will briefly study the following plastics which are used everyday and also some others which are used in building construction.

(a) Thermoplastics

1. Polyvinyl chloride (PVC)
2. Acrylics (Perspex)
3. Polycarbonate
4. Polyethane (polythene)
5. Nylon

(b) Thermosetting plastics

6. Polyester (terylene)
7. Formaldehydes
8. Casein

24.7.1 Vinyls—Polyvinyl Chloride (PVC)

Ethyne is a member of the alkyne group. Hydrogen chloride reacts with ethyne to form vinyl chloride. Vinyl chloride is polymerized to polyvinyl chloride consisting of a long molecular chain represented by $CH_2 - CHCl$ group.

PVC is represented as

$$-CH_2 - CHCl - CH_2 - CHCl - CH_2 \text{ - - - - } CHCl \text{ - - - - }$$

Polyvinyl chloride is one of the cheap plastic material. It is available in three forms, ordinary, plasticized and post-chlorinated. The last one is more resistant to heat up to 120°C which makes it suitable for hot water pipes. Poly Vinyl Chloride can also be made rigid by compounding. One of its popular uses is for pipes for all situations because of its high resistance to most of the chemicals. They are also used to make doors, windows, floor coverings, wall coverings, etc. Details of PVC pipes are given in Chapter 33 (Refer Section 33.3).

When PVC is compounded with rubber stabilisers fillers etc. it becomes less brittle and more temperature resistant. This process is called plasticizing. of pipes, pipes with less than 4% plasticisers are called unplasticized PVC pipes or UPVC or rigid plastic pipes. UPVC pipes can be used in all cases where we have to carry water at ordinary temperatures. For hot water systems, we need special pipes.

Advantages of using PVC pipes. The following are the advantages of PVC pipes (which, nowadays, are very popular) over metal pipes:

1. One of most important advantages of using PVC pipes in water supply systems is their resistance to corrosion to chlorides in water (brackish waters). Whereas GI pipes tend to corrode, PVC pipes do not get affected by these salts.
2. They are unaffected by atmospheric pollution.
3. They provide savings in cost. PVC pipes cost much less than metal pipes.
4. They are light in weight, easy to transport and install. The fixing devices for PVC pipes can be simple because the pipes are light in weight.
5. PVC pipes are smooth inside and have good flow characteristics to convey liquids. The pipes smaller than metal pipes can be used for given flow. Post-chlorinated pipes can be used to carry hot water also. No problem of incrustation arises as in using metal pipes.

6. PVC pipes are extensively used for tubewell construction as they can be buried safely even in corrosive soils.
7. PVC is a good insulator. PVC pipes are extensively used for concealed electrical conduits being an insulator, it is ideal for this use. They are not affected if buried in brickwork, concrete, etc.
8. It is easy to make leakproof joints in PVC pipes. Cutting them and joining them is easy.
9. PVC is being used for doors and windows and are becoming popular for the following reasons:
   (a) They are termite-proof.
   (b) They are not affected by saline air or atmospheric pollution.
   (c) It can be made to close tolerances to make airtight doors and windows necessary for air-conditioned rooms.
   (d) It is an alternate to valuable timber of good quality which is getting scarce.
   (e) They are unaffected by rains when used as external doors.

Some of the disadvantages of PVC pipes are the following:

1. Some of the PVC pipes are brittle and get broken easily in compression. (In places, where "water hammer" can be present as in suction pipes of reciprocating pumps used for pumping water from sumps in residences, it can lead to breakages unless superior plastic pipes are used.)
2. They creep under load much more than metals.
3. Being thermoplastic, ordinary PVC cannot be used for higher temperatures. They are best suited for temperatures up to 80°C under normal pressures.
4. They have high coefficient of expansion as much as ten times that of steel. Sufficient care should be taken for their expansion.
5. They do not weather well in direct sunlight. When installed they should be protected from the direct rays of the sun.

Accordingly, the right type of pipe for each use as described in Chapter 33.

24.7.2 Acrylics—Polymethyl Methacrylate (PMMA). Perspex

This is a group of thermoplastics invented by ICI. The resin is derived from coal, petroleum and water. It is an example of acrylic plastics. Perspex is available in sheets, rods, blocks, etc. They are used for sanitary ware, roof lighting and replacing glass in many situations. The advantages of Perspex can be stated as follows.

1. Colourless Perspex sheets is clear and can replace glass in buildings.
2. It has a high breaking resistance as much as 10 to 15 times that of glass.
3. It is light in weight, weighing only 45 per cent that of glass.
4. It is unaffected by most of the household detergents except by some hydrocarbons and ketones.
5. As it is a thermoplastic, it can easily be formed into different shapes like domes. (Structural engineering models are usually made of Perspex.)

6. It is available in different colours and shades.
7. It is a good insulator. Heat conduction by using tinted acrylic sheets can reduce radiation by as much as 50 per cent.
8. It cuts out ultraviolet rays from sunlight to a very large extent.

As Perspex (as in the case of all plastics) has high thermal expansion, provision should always be made for expansion and contraction when large sizes of this material are used for external windows, skylights, etc.

24.7.3 Polycarbonate (PC)

Polycarbonate is another modern plastic which is as clear as glass with very high impact strength. It can replace glass and is also available in different shades. *Vandalproof glazing* for tall buildings becomes a possibility with this material. They are also used for railway station platform coverings, shop windows, as cover for protection of costly paintings, etc. Polycarbide is at least 250 times stronger than glass. It is used for bulletproof protections in vehicles and VIP public speaking podiums.

24.7.4 Polyethylene (PE)

Polyethylene is also shortened as polythene. It is prepared by polymerization of the ethylene molecule. As shown in Table 24.1, two types of polythene, the low density type and high density type (CDPE and HDPE) are available in the market. Their use is given in Table 24.1 (See also Section 24.14).

24.7.5 Nylon

Nylon is also a condensation polymer, because water is split out between pairs of molecules as the polymer is formed. Two petroleum derivatives are used to make nylon. It is done in two stages, the second process is carried out with heat and pressure in an autoclave. After cooling, nylon appears as chips. By melting the chips and forcing the liquid through tiny holes in a metal disc, filaments are formed. These are stretched between rollers and gathered as nylon yarn, which can be woven into garments, ropes, stockings, etc.

24.7.6 Terylene (Polyester)

Terylene is a thermosetting plastic. As its name "polyester" implies, it is a complex ester synthesized from derivatives of alcohol and benzene. It can be extruded as fibres and woven into fabrics. It is also a condensation polymer. The particular feature of polyester resins is their high resistance to impact. As a resin, it can be combined with glass fibres to produce glass fibre reinforced plastics (polyesters).

24.7.7 Amino Plastics–Formaldehydes

The first to be developed in this group was formaldehyde plastics. *Urea formaldehyde* is a good adhesive used for plywood and decorative laminates. *Phenol formaldehyde* is formed when phenol is reacted with formaldehyde. Resins from this plastic is used in paints, varnishes, water-resistant adhesion for plywood and laminates, electrical fittings, etc.

Phenol furfuraldehyde or *melamine formaldehyde* is obtained from the vapours produced from digestion of substances like rice husk, shells of oats, groundnuts, etc. with sulphuric acid in the presence of prescribed catalyst. This vapour is made to react with phenol to produce the product.

24.7.8 Casin

It is a product obtained from precipitated milk with acids. It is one of the early products used for glues and also used for making plastics for button, buckles, etc.

24.7.9 Epoxy Resins

Epoxy resins are thermosets derived from polymerization of epoxides—an organic chemical from epoxy group, that consists of an oxygen atom bounded by two already connected carbon atoms. They are mostly used as adhesives, coatings and castings.

Araldite is an epoxy or epoxide adhesive. It is used in two parts—araldite GY and a hardener HY. Hardener HY830 is slow-curing and HY850 is fast-curing agent. The two parts GY and HY are mixed together and the mixture gets hardenaed into a solid. It is used for many purposes like sealing cracks in concrete or masonry, as bonding coat for plaster and as epoxy mortar for repairs, etc. (See also Section 26.2.3). It can be injected as a solution into holes where it will get harden. This material used for repair of concrete beams, water proofing and many other uses.

24.8 REINFORCED PLASTICS

In theory, any plastic resin can be reinforced with almost any fibrous material to stabilize, stiffen or otherwise improve the physical character of the plastic resin. There are a wide range of these reinforced plastics and some of the combinations are shown in Table 24.2.

Table 24.2 Reinforced Plastics

S.No	Reinforcement	Plastics materials used
1.	Paper	Polyesters
2.	Asbestos fibre	PVC, polyesters
3.	Glass fibre	Polyesters, polystyrene, nylon

Note. An example of reinforced plastic is *GFRP* which is described below.

24.8.1 Glass Fibre Reinforced Polyesters (GFRP)

GFRP is a good example of how plastics can be reinforced with other materials. It is a combination of glass fibre and plastics. It is one of the very popular reinforced plastic material. It is very appropriate to consider glass fibre which has high tensile strength (as much as 3500 N/mm^2) as a reinforcement. (Its strength is higher than that of any textile material and matched only by carbon fibre). It also stretches elastically up to its breaking point with extension at breaking point of only 5%. It also does not creep. It can stand temperatures up to 600°C. It is resistant to most of the chemicals and is also non-conductive. Glass fibre can be made into many forms such as strands, cloth, wool, rebars, etc.

Usually, polyester is used to impregnate glass reinforcement until a resin-to-glass ratio of 3 to 1 is achieved, when the reinforcement becomes saturated. Polyester is chosen as plastic as it is a thermosetting plastic and has high resistance to impact and strength. Mats made of glass fibre and plastics are called *fibreglass reinforced plastic tissues* or *fibreglass RP tissues.*

Ordinary fibreglass does not act well with cement as they can react with the alkali of cement resulting in drastic reduction of strength of the fibre. Hence, the most widely used method of using glassfibres with cement is the spray method by which the chopped fibres are sprayed on the surface with a simultaneous spray of cement/sand slurry. Such a procedure is used for tanks, claddings, etc.

Eibreglass reinforced plastic is used extensively in building constructions. Some of their uses are as follows:

1. *For waterproofing and dampproofing of roofs, tanks, etc.* The mats made of fibreglass reinforced plastic are used as reinforcing membrane in waterproofing and dampproofing along with bitumen or with special elastomeric paints (see Chapter 30).
2. *For making roof sheets.* The translucent FRP sheets are used extensively for roof coverings.
3. *Water storage tanks.* FRP water tanks are light, easy to install and can be used inside and outside of buildings.
4. *For components in buildings.* Doors, window frames, wall panels, structural sections, temporary shutters, concrete shutters, etc. can be made of this material by suitable fabrication.
5. *For strengthening reinforced concrete bridge decks, slabs, etc.* Carbon fibre and glass fibres with plastics are standard materials for this purpose.

24.8.2 Carbon Fibre Reinforced Plastic (CFRP)

This material is similar to GFRP. The fibres used are strong carbon fibres instead of glass.

24.9 THERMOCOL

Thermocol is a light cellular plastic material used for sound and heat insulation. It is also used in formwork for concreting to form special features in the structure.

24.10 PVC FLOOR SHEETS/TILES

PVC flooring material is used in office buildings as well as in residential and non-residential buildings. It gives a resilient, decordative and non-porous surface which can be easily cleaned but care should be taken to prevent burning stumps (cigarette stumps) to come into contact with PVC floor material. The material should conform to IS 3462-1966. The flooring consists of a blend of *vinyl chloride polymer* or *vinyl chloride copolymer* mixed with binder, filler, pigments, etc. backed with hessian or other woven fabric. It is available as tiles 1.5 to 5.0 mm thick and in rolls 1 to 2 m wide and lengths of 10 metres with varying thickness. Rubber-based adhesives are suitable for fixing PVC flooring over concrete, wooden or metal subfloors. Polyvinyl acetate (PVA)–based adhesives are not suitable when these sheets are used on metal floors and also where there is constant spillage of water.

24.11 LAMINATED PLASTICS—FORMICA

Laminated plastic sheets are used as a hygienic finish for surfaces of cupboards, tables in bars and kitchen as well as for bathroom fittings, wall decorations, etc. They are also heat resistant. They consist of layers of paper impregnated with *thermosetting resins* bonded together under heat and pressure to form hard impermeable sheets. They are dimensionally stable, requires no maintenance except cleaning with a damp cloth. *Phenolic resins* are used for the backing piles and for the top surface (which is usually coloured or patterned), impregnation with *melamine* is carried out. Composite, plywood and chipboard with decorate plastic laminates with backing laminates are also available in the market. Formica company was, perhaps, one of the first companies that started manufacturing such boards and they are sometimes refered as Formica sheets (see Section 15.12).

24.12 USE OF PLASTICS FOR DOORS AND WINDOWS

As good timber is becoming scarce and costly, traditional wood and door systems are being substituted by steel and aluminium structurals from some years back. Nowadays, thermovinyl polymer sections reinforced with steel have also come to the market for these items. They are especially applicable in coastal areas where corrosion of steel windows is a serious problem.

24.13 USE OF PLASTICS FOR ROOFING

Corrugated plastic roofing sheets with and without fibre reinforcements are, nowadays, extensively used for roofing of buildings. Sheets with reinforcements last longer. As they are weak in ultraviolet radiation, nowadays, we get such sheets that are especially treated on the exposed side for such radiation. Such treatment protects the sheet from effects of ultraniolet radiation of sunlight.

24.14 POLYETHYLENE (POLYTHENE) WATER TANKS

Tanks made of high-density or low-density polythene (HDPE or LDPE) are used to make overhead water tanks. The plastic is usually compounded with up to 2.5 per cent carbon black to make it more resistant to the ultraviolet rays from the sun as these tanks are usually kept exposed. Addition of carbon makes it black in appearance. These tanks are generally square or cylindrical in shape. The cylindrical tanks are manufactured by rotational moulding process. Each tank is of a single piece construction. Tanks are provided with integral manhole at the top.

Also openings for inlet, overflow, outlet and drain are also provided. Tanks of capacity from 200 litres (49 to 61 cm in height) to 50,000 litres (180 to 210 cm in height) are available in the market. Generally, for overhead tanks a storage capacity of 70 litres per head for dwelling houses to 135 litres per head for hotels is recommended.

24.15 COMPOUNDING PLASTICS WITH RUBBER

We have already seen that ordinary PVC pipes are called unplasticized (UPVC) pipes. When PVC is compounded with synthetic rubber and other compounds, it becomes plasticized and becomes less brittle. Similarly, polystyrene plastics alone are very brittle but by adding a butadiene rubber compound, their performance is greatly improved.

SUMMARY

Plastic is a modern industrially-produced material with many uses. They are used in all walks of life. Even, the optic lenses used in human eyes as contact lenses or used after a cataract operation are made of special plastic. In building industry, it is used as a component for decoration and also for repair of damages. Study of rubber and plastic is a special field in chemical engineering called polymer technology. In this chapter, we have dealt with only the very elementary aspects of the subject.

REVIEW QUESTIONS

1. Explain what is meant by polymerization? Illustrate the answer with preparation of polythene. Name the type of polymerization that takes place in preparation of polythene?
2. What are the two major classifications of plastics? Distinguish between the two?
3. What are the good properties and shortcomings of plastics as a building material?
4. Explain why terylene is called a condensation polymer. What are its uses?
5. What are thermosetting plastics and thermoplastics? Name two popular plastics of each type and indicate their uses? What are elastomers?
6. What type of plastic is used for heat-resisting decorative laminates like Formica? How is it different from PVC?
7. What are the following plastics and where are they used in building constructions?
   (a) Polyvinyl chloride
   (b) Perspex
   (c) Polycarbide
   (d) Casin
   (e) Urea formaldehyde
   (f) Araldite
   (g) Formica
   (h) Plastomers and elastomers.

8. What are fiber-reinforced plastics? Why glass and carbon fibres are preferred as fibres in FRP? What are the applications of FRP?

9. What are the uses of PVC pipes in house construction? Discuss the advantages and disadvantages of using PVC pipes instead of GI pipes in buildings?

10. How plastics are used in manufacturing of paints? What are the advantages of these paints over conventional oil paints?

11. What is araldite? How is it marketed? What are its uses in civil engineering construction?

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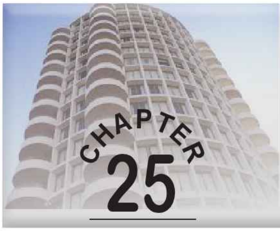
[1] IS 13592–1992: *Unplasticized PVC (UPVC) Pipes for Soil and Waste Discharge System Inside Buildings Including Ventilation and Rainwater System Specification.*

[2] IS 14735–1999: *UPVC Injection Moulded Fittings for Soil and Waste Discharge System for Inside and Outside Buildings Including Ventilation and Rainwater System Specification.*

[3] IS 3462–1986: *Specification for Unbaked Flexible PVC Flooring.*

[4] IS 12701–1996: *Specification for Rotational Moulded Polyethylene Water Storage Tanks.*

[5] (Also see References under Chapter 33).



CHAPTER 25

Asphalt, Bitumen and Tar

25.1 INTRODUCTION

Asphalt, bitumen and tar are hydrocarbons. Asphalt and bitumen are petroleum products whereas tar is a dark coloured product obtained from destructive distillation of organic substances like coal, wood or bituminous shales. Asphalt also appears in nature as natural deposits. These materials are used very much in building and road constructions. This chapter deals briefly with these materials.

25.2 ASPHALT

Asphalt is defined as a *mixture of bitumen with a substantial proportion of inert mineral matter*. Bitumen is the binding material in asphalt. The following are the two types of asphalt.

1. Natural asphalt
2. Residual asphalt (petroleum asphalt)

Natural asphalt occurs as fossil deposits in places like lakes in Trinidad at depths of 3 to 60 m. It contains 40 to 70 per cent pure bitumen with about 30 per cent water content. ***Residual asphalt*** is obtained from distillation of petroleum oil with an aspheric base. The residue left will also be asphalt.

Mastic asphalt is prepared by mixing the required mineral filler (like limestone dust, sand or grit and coarse aggregate) with black bitumen heated to a liquid form. On cooling, it consolidates to a hard elastic block. This can be reheated and used in pavements and for other uses. It is tough, durable, non-absorbent, dampproof, non-inflammable and noiseless. It is very much used for waterproofing works in building construction (See Chapter 30).

Asphaltic cement is bitumen or asphalt or their blend with flux oils having adhesive qualities suitable for making mastic asphalt. (The terms asphalt and bitumen in practice mean the same substance except that asphalt has considerable amount of inert materials compared to pure bitumen.)

25.2.1 Uses of Asphalt in Buildings

Asphalt is used in buildings for the following works:

1. Roofcovering, flashing, waterproofing of roofs.

2. Damp roof courses
3. Flooring material
4. Tanking of basement floors (building water barriers in basements) (See section 25.7)

25.3 BITUMEN

Bitumen is the product obtained by fractional distillation of crude petroleum as an end product. Bitumen becomes soft at moderate temperatures. It can be modified by heating until it becomes a liquid and then passing air under pressure by which all the volatile compounds in it can be driven out. The product is called "*blown bitumen*" (R grade). This product has a high softening point so that if exposed directly to the sunrays for any length of time, it does not get soft. At ordinary room temperatures, it is very hard. It is also soluble in some solvents. Blown bitumen is the product that is commonly used for manufacturing joint fillers and bitumen felt, which are used for waterproofing and dampproofing. Bitumen is also extensively used for surfacing of road and airport pavements. Bitumen is available in the following forms:

1. ***Straight run bitumen.*** It refers to bitumen distilled to a definite viscosity of penetration which does not require further treatment like heating.
2. ***Blown bitumen.*** It is described above.
3. ***Penetration grade.*** It is the basic form of bitumen and has to be heated before application.
4. ***Cutback bitumen.*** It is the bitumen combined with other petroleum distillates. This may be regarded as means of applying penetration-grade bitumen at lower temperatures.
5. ***Bitumen emulsion.*** It is a product in liquid form formed in aqueous medium and stabilizing agents. This is also another means to obtain bitumen into a liquid form so that it can easily be applied at ambient temperature.
6. ***Plastic bitumen.*** It consists of bitumen thinner and suitable filler made into a plastic form. As it is plastic, it can be used for filling cracks in masonry, stopping leakages, etc.
7. ***Cutbacks.*** They are bituminous materials in solvents.
8. ***Residual bitumen.*** It is a solid substance at normal temperature and is obtained as a residue during distillation of high-resin petroleum.

25.3.1 Modified Bitumen

Modified bitumen, is obtained when bitumen is combined with plastics. As in this process, bitumen is not heated to high temperatures in its manufacture, the lighter oils are also preserved in modified bitumen, thus improving its flexibility and resistance to weathering. Polymerized bitumen are generally of two types—Atactic Polypropylene (APP) and Sequenced Butadiene Styrene (SBS). The former is a plastomer while the later is an elastomer. APP-modified bitumen is generally stronger and stiffer then SBS-modified bitumen, which has greater flow for expansion and waterproofing qualities. Both have high tolerance for ultraviolet rays. Hence, nowadays, these modified-polymer bitumen are used (instead of blown asphalt) for preparation of waterproofing bituminous felts used for waterproofing of roots.

25.3.2 Specification of Grade

Bitumen is specified by the term "penetration" (example penetration grade 80/100). Penetration-grade bitumen is semi-solid at ambient temperature and requires to be heated to make it fluid enough for applications such as for waterproofing roof surfaces. As we will see in Section 25.9, the specification 80/100 refers to the penetration of a standard needle at a temperature of 25°C.

25.3.3 Bitumen Mastic

Bitumen mastic is prepared in the same way as asphalt mastic described in Section 25.2.

25.4 TAR

Tar is different from bitumen and the different types of tar can be obtained from the following procedures.

1. ***Coal tar*** is obtained by heating coal in closed iron vessels to form coke. On condensation of the escaping gases, we get *coal tar*. This tar is mostly used for roads.
2. ***Wood tar*** is obtained by distillation of pine wood and other resinous wood. It contains creosote oil and hence has strong preservative property for wood and also repels termites if applied on *wooden posts buried in the ground*.
3. ***Mineral tar*** is obtained by distilling bituminous shales. It has less volatile matter than the wood tar.

In addition to use as a preservative of wood, because of its very good adhesive power, it is also used as a water proofing paint in many situations.

25.5 COMPARISON OF ASPHALT, BITUMEN AND TAR

Table 25.1 shows comparison of the properties of asphalt, bitumen and tar.

Table 25.1 Comparison of the Properties of Asphalt, Bitumen and Tar

Property	Asphalt	Bitumen	Tar
Existing state	Solid or semi-solid	Usually solid at normal temperatures	Solid as a viscous liquid
Colour	Blackish brown	Dark black	Deep black
Effect on heating	Burns with smoke and becomes plastic at 250°C	Becomes liquid on heating	Becomes less viscous on heating
Adhesive power	Not much	Good	Very good
Carbon content	Less	More	Most
Setting time	Not much	Not much	More
Resistance to acid and water	Good	Good	Less

25.6 USE OF BITUMINOUS PRODUCTS IN ROADWORKS

A graded stone mixture coated with tar is used for *tar macadam* and when the mixture is coated with bitumen, it is called *bitumen macadam*. Tarmac has a slightly black appearance in comparison with bituminous macadam. The choice depends on the cost and availability. Bituminous products are extensively used for pavements, walkways, etc. Mastic asphalt as described in Section 25.2 is used in city roads where we need a very smooth riding surface.

25.7 GENERAL APPLICATIONS OF BITUMINOUS MATERIALS

There are many uses of bituminous materials in civil engineering works. Some of them are given below.

1. ***For paints.*** They are used for manufacture of bituminous paints and other surface treatments. The industrial blown or R grade of bitumen is mainly used for this purpose.
2. ***Roofing.*** Roofing felts and shingles (coverings of roof) are made of fibres or plastics impregnated with penetration-grade bitumen and coated with blown-grade bitumen.
3. ***Damp proofing.*** Prefabricated mats which are sprayed with blown bitumen are used for dampproofing. They are also used as small "water-retaining, bituminous walls" at refuse disposal sites to prevent pollution from spreading.
4. ***Tanking of basements.*** Asphalt and bitumen are the usual choices for water proofing of basements known as tanking of basement (See Section 30.4).
5. ***Protection of structures.*** It is used as a protective coating (by impregnation) for concrete elements such as piles, slabs, etc. Over these coatings, organic binders of 10–15 mm thickness are also applied to prevent the bitumen from eroding off.
6. ***Pavements.*** Bituminous materials are extensively used for the construction of roads, runways, taxiways, etc.
7. ***Preservation of stones.*** Bituminous materials are some of the materials used for preservation of stonework from attack by salts and other substances present in the ground or in the atmosphere.

25.8 BITUMINOUS FELTS

Bituminous felts are mats impregnated with bitumen and are described in Chapter 30 under waterproofing materials.

25.9 SPECIFICATION OF BITUMEN

One of the specifications for waterproofing in building work is as follows: "The surface shall be painted uniformly with bitumen of approved quality such as "residual type", "petroleum bitumen, penetration 80/100, hot cutback bitumen or equivalent after heating to the required temperature as per specification of the manufacturers shall be used". Thus, the term penetration is important in the specification. There are many tests prescribed for bitumen to be used in road construction. The two important tests for building construction are the penetration test and the softening point test. These are given below.

1. ***Penetration test.*** It is a measure of the hardness of the bituminous materials. It is the depth in millimetres to which the standard tapered needle penetrates vertically under a load of 100 g in 5 seconds at a temperature of 25°C. The test is shown in Figure 25.1. This test measures only the consistency of the bitumen binders and has no relation to its binder capacity. The specification 80/100 means that the above penetration is between 80 to 100 mm.
2. ***Softening point test.*** It is the temperature at which the bitumen softens. The apparatus and method of test are shown in Figure 25.2.

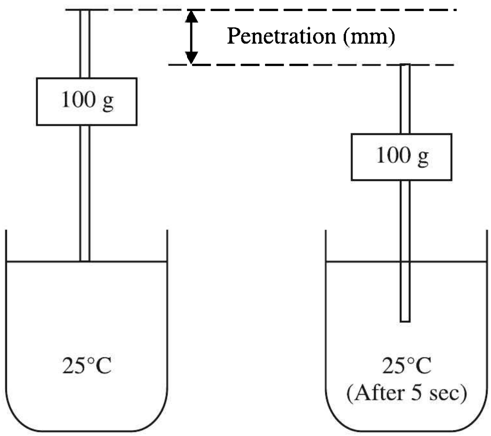


Figure 25.1 Measurement of penetration of bitumen.

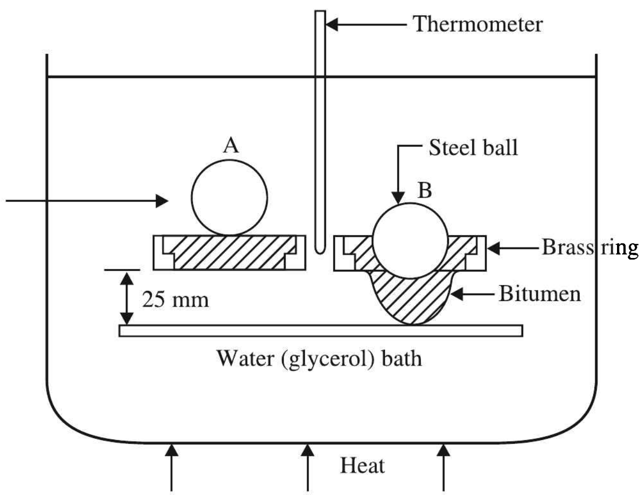


Figure 25.2 Ring and ball test for determination of softening point temperature of bitumen.

SUMMARY

Asphalt, bitumen and tar are so far the most economical materials for waterproofing of buildings. They are used not only in the raw form but also in modified form for paints and manufacture of membranes (sheets) and other products. One of the new materials in the group is the modified bitumen which is bitumen combined with plastics.

REVIEW QUESTIONS

1. Distinguish between asphalt, bitumen and tar? What are the uses of tar in building construction?
2. Define the following terms: Penetration-grade bitumen, blown bitumen, cutback bitumen, straight-run bitumen, modified bitumen.
3. Describe the penetration test for bitumen. What characteristic does this value indicate?
4. What is blown bitumen? Why is it preferable to use this bitumen for roof work? What is modified bitumen and explain its use in building construction.
5. How would you determine the softening point of bitumen?

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[3] IS 216–1961: *Specification for Coal tar Pitch.*

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[5] IS 4365–1967: *Code of Practice for Application of Bitumen Mastic for Water-proofing of Roofs.*

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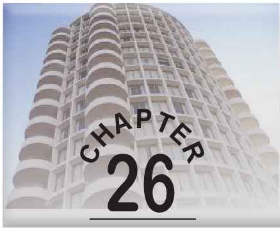

CHAPTER 26

Adhesives, Sealants and Joint Fillers

26.1 INTRODUCTION

An *adhesive* is a substance used to stick two or more parts together so that they behave as a single unit. *Sealants* are substances used to seal or fill joints. *Joint fillers* are used in those places where the sides of the joint are subjected to relative movements. Traditional materials like cement mortar are too inflexible to perform well to seal joints which move. Sealing compounds are designed to remain sufficiently elastic or plastic to follow the movement of the joints while adhering firmly to the sides. Adhesives and sealants are used in many places in civil engineering construction. In this chapter, we will study these materials briefly with reference to a few of their applications in building construction.

26.2 ADHESIVES

There are many situations such as in timber construction where we have to use adhesives to stick one piece to another. The use of adhesives in building construction is well established and today, there are many specially-designed adhesives in the market for different types of work. Adhesives have advantage over fixing by mechanical means like drilling, plugging, nailing, etc. Modern plastic materials (like PVC pipes) are always joined by adhesives. Some adhesives can be used only for one type of material whereas others can be used with many materials. We will briefly deal with the commonly used adhesives to get an idea what these materials are. Adhesives can be of the following three types:

(a) *Organic adhesives.* These adhesives are made from animal protein, blood albumen, milk casein or starch, etc.

(b) *Synthetic adhesives.* These adhesives are made from natural resins or from manufactured plastic resins such as melamine resins, urea resins and phenolic resins.

(c) *Rubber-based adhesives.* These adhesives are materials in which rubber is dissolved in benzene or ground with other resins of plastics.

We will examine adhesives from the point of view of their uses.

26.2.1 Adhesives Used in Timber Construction

Formaldehyde adhesives of phenol, urea and resorcinol are the accepted products for use in woodwork. It is used to make plywood and laminated products. It is also used in timber joints to strengthen the joint. The following four types or grades of adhesives are recognized:

(a) *Weatherproof and boilproof* (WBP)—Highly resistant to micro-organisms, cold, boiling water and dry heat.
(b) *Boil resistant* (BR)—inferior to WBP but resistant to weather.
(c) *Moisture resistant* (MR)—only moderately resistance to weather.
(d) *Interior* (INT)—to be used in the interior only.

Only certain phenolic resin adhesives fall into the first group. We should be careful to check when we buy plywoods, flush doors, etc. as to what adhesives are used for their preparation. Plywood used for wet situations should be WBP grade. *Fevicol* is a synthetic resin adhesive used in furniture industry in India. It is resistant to heat and water.

26.2.2 Adhesives Used for Ceramic Tile Fixing

Ceramic tiles are very much used for floors and walls as floor tiles and wall tiles. They are used in the interior as well as the exterior for cladding. For internal tiling, traditional cement/sand mortar is still used in many places. However, the necessity to speed up the work and the need for curing cement works as well as non-availability of good workers has introduced new products for tile fixing. They provide greater bond strength, reduction in weight of fixing material and make the work cleaner and quicker. The need to soak the tiles in water and errors due to variation of the composition of the mortar are also eliminated. They are usually one of the following products:

1. Natural or synthetic latex-based mortars
2. Cement-based specially formulated thick bed and thin bed mortars with latex
3. Synthetic resin emulsion
4. Epoxides

Note: Of the above-mentioned products, the latex-based adhesives are, nowadays, very popular in construction.

26.2.3 Adhesives Used for Joining Concrete

There are many instances where concrete has to be joined with concrete or other materials. Epoxide adhesives (see Section 24.7.9) are the best adhesives to be used for bonding broken concrete, setting metal posts in concrete as in staircases, etc. It saves time in construction, as the bond strength is built up within 24 hours. All epoxide adhesives used for buildings come in two parts. The efficient mixing of these two parts and the application of the mixture before the reaction between them starts are important factors in its use. The design of the joint should also provide means to support the parts to be joined properly till hardening has completed. *Araldite* available in many forms is commonly used for concrete work (see Section 24.7.9). The two parts to be used for araldite adhesive are marketed as

1. Araldite (generally araldite GY250 is commonly used)
2. Hardener (HY 830, HY 850, etc. are hardeners, the latter is fast curing)

Additives like silica flour are also added if required. As the pot life of the mixture is only 90 minutes at 25°C and 45 minutes at 35°C, the mixed substance should be applied to the surface as quickly as possible. For very good bonding to the concrete chemical etching of the concrete surfaces by using 15% HCl followed by thorough cleaning and drying prior to application of the adhesive gives very good performance. (Nowadays, epoxy coatings are also used for coating steel rods to be used in reinforced concrete construction for protection against corrosion.)

26.2.4 Adhesives for External Claddings

External claddings or facades are important items in tall buildings. Stones, tiles, mosaic, etc. can be fixed with proper adhesives. Stone facings are usually fixed by metal dowels. Coloured special glass fixed in aluminium or steel framework is very popular these days as cladding for tall buildings. Till recently, for these claddings or faeade glass was fixed inside aluminium or steel framework. In this type of work, the frames were visible from outside the building. Special adhesives have now been developed so that the glass or special plastics (like polycarbides) can be fixed directly on to the frames by adhesives so that the structural framework becomes invisible from the front elevation and thus, presenting a continuous glazed surface.

26.3 SEALING COMPOUNDS (SEALANTS) AND LINSEED OIL PUTTY

As already pointed out, sealants are used to fill gaps in joints such as window-wall joints, in glazing, lap joint of roof sheets, etc. Joint fillers should allow the joints to move to a certain extent but the material should always maintain its joint-sealing capacity. This special property is necessary for joint fillers and will not be present in brittle materials like concrete, plaster, etc.

The traditional material used for filling joints between glass to frame or panel to frame is linseed oil putty, oil-based mastics, etc. *Linseed oil putty* for window glazing is prepared by first mixing one part of white lead with three parts of fine powdered chalk and then adding boiled linseed oil to the above mixture to form a stiff paste. Varnish is also added to the pasts at the rate of one litre of varish to 18 kg of paste. This pulty is still used in India but only in low cost and ordinary building constructions. Many modern sealants are available in the market for joint filling purpose of high rise building. They are marketed in the following forms:

1. *Preformed strip.* They are supplied as preformed tapes.
2. *Mastics.* They are high viscosity liquid form applied by using a putty knife or by hand-operated guns.
3. *Semi-elastic sealants.* They are superior to mastics invariably applied by special guns.
4. *Elastomeric sealants.* They are the most efficient type of sealants usually supplied in two parts to be mixed at site and generally applied by special guns. Elastomeric silicon sealants are very efficient and popular.

26.4 COMPRESSION AND EXPANSION JOINT FILLERS IN BUILDINGS

Design of joints that move like expansion joints and detailing of joint fillers for these joints are important. The joints are usually filled with blocking strips at the back so that the *adhesion* *is between two opposite sides only.* Three-side adhesion destroys the adjusting power of the sealant and leads to failure of the joint as shown in Figure 26.1. This factor is very important in installation of expansion joint fillers.

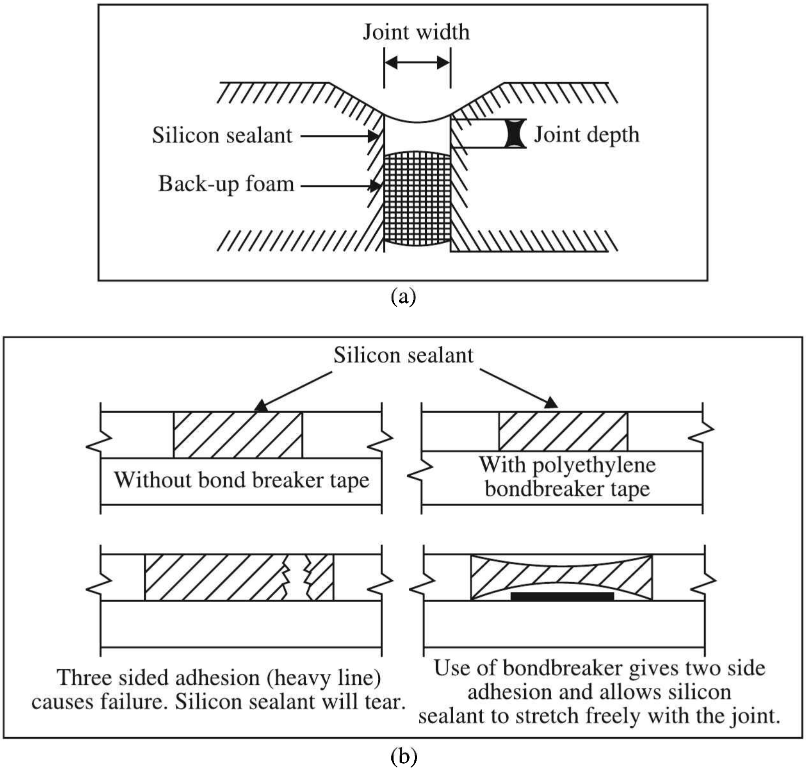

Figure 26.1 (a)Deep joints should be filled with back-up foam of polyurethane (PU) or polyethylene (PE) to reduce the depth of the joint. (b) Polyethylene tape used for two side adhesion which allows the silicone sealant to stretch freely in the joint.

Compression and expansion joints have to be given in many parts of a building. Movement joints are provided in concrete buildings as changes in temperature and humidity cause change in length. The joint width to be provided for expansion is usually twice the calculated movement due to temperature variation, or at least 25 mm. Cellular back up material is always provided to control depth of joint and avoid three-side adhesion (Figure 26.1(a)). Adhesion should be only between the two opposite sides as shown in Figure 26.1. This back up material should be a compressible gap filling material like high density polyethylene or polyurethane strip. This prevents backadhesion. (Thermocol should not be used as it gets destroyed by insects.) Polysulphide silicon or other sealants which can undergo movements of 25 per cent in compression and 25 per cent in tension are available and are commonly used in R.C. construction.

Another example of using sealants is while providing cladding or facing for a building with stone slabs fixed to an existing wall, the stones are generally fixed to the wall with non-ferrous cramps (metal bar with bent ends). To allow for movements in large size walls horizontal compression joints must be formed at intervals by fixing strips of butyl rubber compound or preformed bituminous-foamed polyurethane sections. Vertical expansion joints are first filled with bituminous-foamed polyurethane strip or other material set deep into the grooves and then the gap is filled with gunned in polysulphide or silicon rubber sealants. As already stated in the expansion joints, three-side adhesion should be avoided, otherwise adhesion at the back will cause failure of the joint.

SUMMARY

A knowledge of modern adhesives, sealants and joint fillers is necessary in modern building construction. New materials and methods of joining them are growing rapidly and a building engineer should keep track of these advances. Design of joints for compression and expansion is studied in building construction.

REVIEW QUESTIONS

1. Distinguish between adhesives, sealants and joint fillers by giving examples of such work in building construction.
2. What was the traditional material used for fixing of glass to windows? What modern materials are used these days for such works?
3. Give a brief account of the sealants and joint fillers used in building construction.
4. Where do you use adhesives in building construction? Give a brief account of the usual adhesives used.
5. Explain why joint fillers should always be provided with a suitable back up material to prevent three-side adhesion. What are the necessary properties of the joint fillers and the back up materials?

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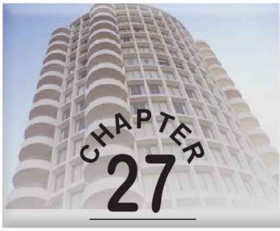

Ceramic Products

27.1 INTRODUCTION

The term *ceramics* means the technology and the art of making objects with clay and similar materials by treating with fire. It is derived from *Keramos* meaning potter's clay. Clay products, refractories and glass come under this subject. The subject is so vast that a separate discipline of study called Ceramic Engineering is available in many universities for specialization. In this chapter, we will deal briefly with clay and ceramic products that are generally used in building construction. As tiles in various forms are the principal ceramic products used in buildings, we will deal with roof and floor ceramic tiles in detail.

27.2 CLAY FOR CERAMICS

Clay is defined as very fine soil particles. It is a product of chemical weathering of various types of rocks. The coarser particles in soil produced by weathering are predominantly quartz– the principal constituent of sand. The finer particles of clay are, however, made of various clay numerals. According to the minerals present in the clay, there can be different types of clay deposits on the surface of the earth. Each of the special ceramic products requires its own type of special clay so that ceramic factories producing these products are usually situated near places where such clays are available. Thus, even though ordinary earthenwares can be made from many types of ordinary clay. Kaolin, a fine white clay is required to manufacture *porcelain articles*. Refractory clay, which is special heat-resisting clay, is necessary for making refractories for chimneys and ovens. We have already seen in the chapter on clay bricks the changes that take place when clay is heated to very high temperatures.

27.3 SOME TERMINOLOGIES

1. ***Earthenware.*** The term "earthenware" is used for clay products burnt at lower temperatures. They are coarse as well as opaque in character. Sometimes the clay has to be mixed with some fine sand to reduce shrinkage. Ordinary cooking pots and pans usually used in villages come in this category.
2. ***Stoneware.*** Stoneware is a product of refractory clay to which a large amount of ground stone and pottery is added. It is burnt at higher *temperature to vitrification*. Stoneware jars are very popular. Earthenware and stoneware together is called *pottery*.

3. ***Porcelain.*** The term "porcelain" is used to the white translucent, strong ceramic material made of kaolin and feldspar with transparent glaze. They are produced by firing at very high temperatures. As porcelain is white in colour, it is also called *whiteware*. Dinner plates, tea cups and saucers come under this category.
4. ***Terracotta.*** It is a hard brownish, unglazed vitrified ceramic material used for architectural ornamentation. Some terracotta products are made by mixing the clay with sawdust, etc. and firing it. The sawdust burns and leaves a porous vitrified clay product.
5. ***Fainzee.*** Faenza is a city in Italy. Pottery that was once popular in that city is Fainzee. It is eartheware or pottery to which heavy glazing has been applied and fired at a second time. It differs from porcelain in the degree of baking and hence porosity. Fainzee has a porous shell and porcelain a solid shell. (It is the various degrees of baking with different proportions of the working mass that produce the various products from the same raw material.)
6. ***Glazing.*** The provision of a transparent or opaque glass like coating is called glazing. The coating is only 0.1 to 0.2 mm thick. It improves the appearance, provides a smooth surface and protects the surface from atmospheric as well as chemical action. When glazing is thin in tiles like floor tiles subjected to heavy traffic, it does not last long. The common methods of glazing are as follows:
   (a) *Glazing by adding materials.* Oxides and salts of various metals can be added to the chosen clay and mixed intimately. On firing, we get a coloured product with glaze. Addition of copper oxide gives a green colour and addition of iron oxide gives a red colour to the tile.
   (b) *Salt glazing.* It is a transparent glazing obtained by putting common salt into the kiln at the right temperature of firing the clay product. The salt is vaporized and enters into the pores of the clay material. It combines with the silica in the clay to form soda silicate which combines with the alumina lime and iron in the clay to produce a permanent, thin and transparent surface coating, the salt glaze.
   (c) *Lead glazing.* This glazing is superior to salt glazing. It consists of an article which is previously burnt and dipped in a bath containing oxides of lead and tin. When reheated, the lead and tin melt to form a thin glass coating.
   (d) *Opaque glazing or enamelling.* In this process, a solution called *slip* is first prepared by firing borax, kaolin, colouring matter, feldspar, flint, lead oxide, etc. to a molten glass. This is poured in water and the resulting material is ground with more feldspar, flint, lead oxide into a creamy consistency. Articles to be glazed are first fired and cooked to form "*biscuits*". These biscuits are then dipped in the slip and again fired. Sanitary articles are usually glazed by this process.
7. ***Tiles.*** The term "tiles" was originally meant for thin slabs of burned clay which were used to cover roofs as well as floors. Today, all materials of thin slabs of baked clay of all shapes and sizes are called tiles. Thus, we have terrazzo tiles made of concrete and rubber tiles made of rubber to be used on floors and clay tiles to be used on roofs and floors.

We can have many types of tiles made from clay. We will deal briefly only with the following types of tiles:

1. Common clay tiles for floors
2. Clay tiles for terraces
3. Clay tiles for ceiling
4. Glazed tiles for floors and walls
5. Vitrified tiles
6. Common clay roof tiles
7. Country roof tiles

(Encaustic tiles are the tiles initially painted with colours and the colours get fixed to the tiles with heat.) In the following sections we will deal with ceramic floortiles.

27.4 COMMON CLAY FLOOR TILES

These tiles were used extensively in India in former days. They were made from fine special blue clay which enables the tiles to be made thin and the surface to be smooth. To make the tiles hard and impervious, a mixture of ground glass and potteryware may be added to the clay in the required dose. Generally, these materials are mixed together thoroughly and extruded in the shape of slabs. These slabs are put into moulds and pressed to the required shape. Thereafter, they are fired at a temperature of about 1300°C. They can also be hand-moulded and pressed by a mechanical press into shape. They are generally salt glazed to give a good appearance. Floors made of these tiles, unlike cement floors, are more suitable for walking barefooted.

27.5 CLAY TERRACING TILES

Terracing tiles are flat tiles made in the same way as the floor tiles but they are not usually glazed. They can be hand-made or machine-pressed from well-weathered and well-prepared clay and burnt in a kiln. They should be burnt uniformly. The usual sizes of these tiles are 20 × 20 cm, 20 × 10 cm and 15 × 15 cm. The thicknesses are 15 mm and 20 mm. (The tolerances allowed are ±5 mm in length and ±2 mm in thickness). These tiles are to be made according to IS 2690–1964. Nowadays, the large sized tiles are preferred over the small ones.

27.6 CLAY CEILING TILES

These tiles are usually placed on reepers. Over these ceiling tiles, Mangalore tiles are laid. They are generally given a flower pattern decoration on the exposed faces. These tiles should conform to IS 1464–1959.

27.7 GLAZED CERAMIC TILES

Glazed ceramic tiles are made from special ceramic clays in two operations. Firstly, the body of the tile is made and fired at around 1200 to 1300°C. The products are called “biscuits”.

These biscuits are then coated with glaze, decorations, etc. and again fired in ovens to give opaque glazing. The glazing can be of many types. Earthernware glazed tiles are made from special clays or enamels. Coloured enamels can be of two types—bright and glassy. It can be eggshell or mat finish.

Till recently, glazed tiles were exclusively used as *wall tiles* for bathrooms in hospitals, etc. where there is no traffic, (on which people do not walk). However, with the development of more and more durable glazings, these tiles are, nowadays, also used for floors with light traffic as in residences. With the advent of better technology, glazing thicker than before are being produced. Such large size tiles are being used for flooring in offices, airports, etc. Wear of the glazing of these tiles depends on the temperature of firing and thickness of glazing. When selecting glazed tiles as floor tiles, care should be taken to examine the thickness of glazing. Fully-vitrified tiles as described below are, nowadays, preferred over glazed tiles as floor tiles as they do not wear off as in the case of glazed tiles.

27.8 FULLY-VITRIFIED TILES

When special clay is mixed with oxides and burnt *to very high temperatures* the clay becomes vitrified and we get coloured vitrified tiles. In contrast to ordinary glazed tiles, where the glazing is only on the top surface, these tiles are wholly made of vitrified clay. Special techniques can be used in its manufacturing to get special surfaces. Such tiles fare well as floor tiles even in moderately heavy traffic. Many ceramic companies now make fully-vitrified tiles in India. Their water absorption is only 0.5 per cent. This tile bridges the gap between ordinary ceramic tiles and marble floors. These tiles can be distinguished from glazed tiles by examining the broken section of the tile. The edges of these tiles are usually ground again after manufacturing so that the tiles can be laid with very close joints. These tiles are especially used in kitchen floors as ordinary ceramic tiles are brittle and the fall of any heavy object is liable to chip the ceramic tiles.

27.9 PORCELAIN TILES

The latest addition to ceramic tiles are porcelain tiles. They are available in many forms as plain, coloured and also with decorative patterns and sizes. They are rather expensive compared to the traditional floors. They are very decorative but brittle in its behaviour.

27.10 CHOOSING FLOOR TILES

There are so many alternative types of tiles for floors and we must choose the type of tile to be used with great care. The appearance of a finished building will be very much influenced by the flooring material used and at the same time, the floor material should suit the type of building for which it is chosen. Expensive tiles do not go well with low cost buildings and similarly cheap tiles do not suit prestigious buildings. The following are some of the important considerations in choosing ceramic floor tiles (see also Chapter 31).

1. ***Water absorption.*** The body of *ordinary clay tiles* can have an absorption capacity more than 10 per cent of its weight and a low modulus of rupture. On the other hand,

for stoneware tiles produced from a mixture of clay and special silicon materials, the water absorption will be low in good tiles, it should not be more than 2.5 per cent.

2. ***Quality and thickness of glaze.*** The quality and thickness of glaze used are very important factors in choosing the glazed floor tile. It is good to remember that bright colours used for ceramics need a body with high expansion coefficient and this can be achieved easily only in a porous and relatively low strength ceramics. Hence, with such backings, very bright coloured tiles do not wear out very well in heavy traffic areas.
3. ***Wall and floor tiles.*** Until very recently, the most glazed clay tiles made were suitable for walls. Floors with people walking on it have traffic and hence, floor tiles should have better wearing surfaces. Even in floors, we should distinguish between places of light traffic as in dwellings and places of heavy traffic such as shopping centres, railway stations, pathways, etc. The flooring material chosen should match the traffic. While choosing glazed tiles for floors, much care should be taken to examine the quality and thickness of glazing. Otherwise, the flooring will deteriorate in a short time.
4. ***Aesthetics.*** In addition to ceramic tiles there are many alternatives for floors like marble, terrazzo. The material and pattern of tiles chosen should always satisfy aesthetics.
5. ***Function.*** The floor material should satisfy its function. In a computer room, we generally go in for a resilient floor like PVC or linoleum floor. Similarly, we will prefer woodflooring for a dance floor. In bathrooms, we usually use marble floors. In workplaces, like kitchens, the floor should not be brittle.
6. ***Cost.*** The floor material should match the cost of the construction envisaged. For high class building like kitchens, we should use top class tiles. (Ceramic tiles are again dealt with in Section 31.2).

27.11 COMMON CLAY ROOF TILES

In this section, we will deal with the commonly used roof tiles. Clay roof tiles are made of plastic clay different from brick clay. For making tiles, the clay has to be moulded to sections thinner than bricks. There are many types of clay *roof tiles*. They are mostly used for covering sloped roofs. We will deal with the following types of roof tiles which are more popular than the other types in India:

(a) Mangalore pattern roofing tiles
(b) Half round country tiles (Spanish tiles)
(c) Allahabad tiles (Italian tiles)

27.11.1 Mangalore Pattern Roofing Tiles

Mangalore tiles are of various shapes and dimension. They overlap on the tile below and also lock with the adjacent tile as shown in Figure 27.1. The detailed specifications are given by IS 654–1972. These tiles are very popular in South India, especially in Kerala and Tamil Nadu. Table 27.1 illustrates the various dimensions of Mangalore tiles.

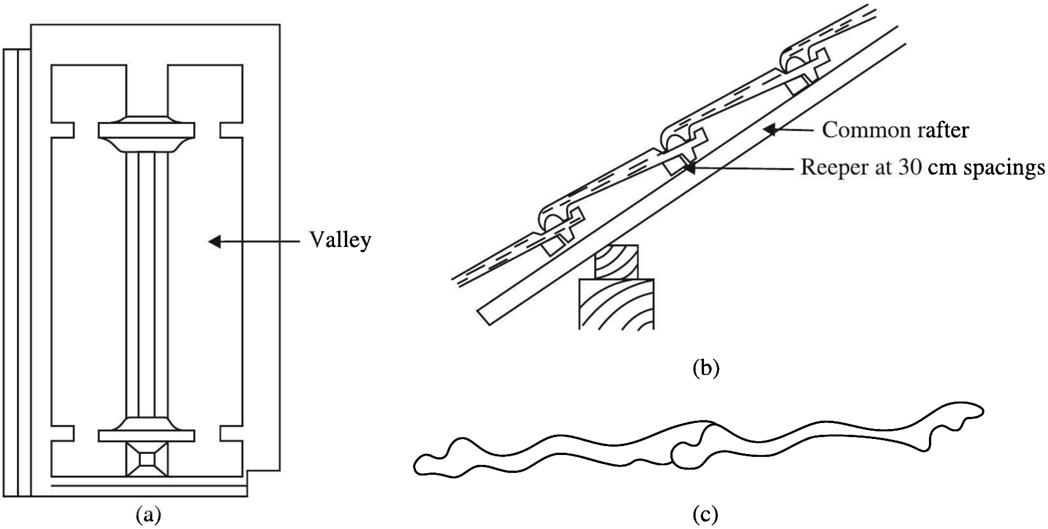

Figure 27.1 Mangalore tiles (a) Plan view of back of tile (b) Arrangement of tiles lengthwise (c) Interlocking of two tiles breadthwise.

Table 27.1 Dimensions of Mangalore Tiles

Type No.	Overall (mm)		Effective (mm)	
	Length (mm)	Width (mm)	Length	Width
1.	410	235	Minimum overlap	Minimum overlap
2.	420	250	60 mm	25 mm
3.	425	260		

These tiles are classified into two classes depending on water absorption and breaking load as shown in Table 27.2.

Table 27.2 Classification of Roofing Tiles

No.	Characteristics	Requirements	
		Class AA	Class A
1.	Water absorption	19%	24%
2.	Breaking load (kg) Individual and average	102	82

The usual tests made to access the quality of the tiles are the following:

The flatness of a tile is tested by placing the faces of the tile on a plane surface. The gap at the corners shall not be more than 6 mm. There should be at least two *battern lugs* provided for the tile. (These lugs should have base thickness not less than 15 mm with top thickness not less than 10 mm and a projection from the tile shall be 7 to 12 mm. Similarly, there should be two eave lugs. They should be shaped so as to fit into the corrugations of the next tile as shown in Figure 27.1.

It is the practice to provide at least one hole in one of the crossribs near the eve end for securing the tile to the reeper or batten with a wire so that they are not lifted off by high winds (This is especially important in cyclonic regions). (Laying of Mangalore tiles is a standard specification No. 44D in Tamil Nadu Building Practice).

27.11.2 Clay Half Round Country Tiles (Spanish Tiles)

Half round country tiles are made in Indian villages by potters and are commonly used in villages. (They are also refered as Spanish tiles). These are laid in pairs as *undertiles* and *overtiles* as shown in Figure 27.2.

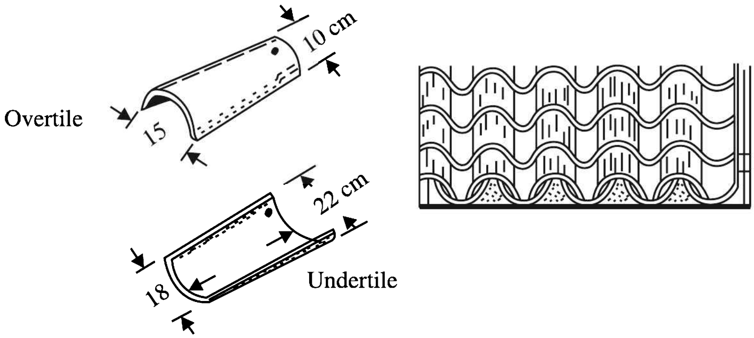

Figure 27.2 Country (Spanish) tiles.

The undertiles are laid at a spacing of 26 cm with spaces not less than 75 mm between their edges and over them the overtiles are laid. The undertiles will be laid with their narrow end towards the eves, whereas the overtiles will be laid with their wide end towards the eves. These tiles are also sometimes placed over A.C. or G.I. sheets as ornamentation.

27.11.3 Allahabad Tiles (Italian Tiles)

Allahabad tiles (also called Italian tiles), consist of two types–the bottom and top tiles. The bottom tiles are flat, tapered with upturned flanges at the sides. The overtiles are half round and tapered as shown in Figure 27.3. The trough tiles are 30 cm × 40 cm in size and the

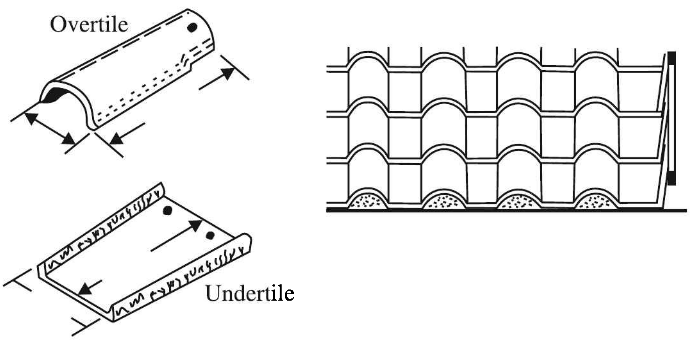

Figure 27.3 Allahabad tiles.

top tiles are 15 cm × 35 cm in size. Both are slightly tapered towards one end. Specifications for laying of these tiles are given in I.S. and CPWD specifications.

27.12 CERAMIC SANITARY APPLIANCES

Sanitary appliances are also made of ceramics. They are made of high grade ceramics made from a mixture of suitable clays and finely ground minerals such as quartz and felds par. (They are known as vitreous sanitary appliances. The word "vitreous" denotes like glass in hardness, brittleness, appearance, etc.)

There appliances are of the following two types:

1. Soil appliances for collection and discharge of *excretory matter*. Water closets, urinals, bidets, etc. come under this class.
2. Waste appliances for collection and discharge of *waste water* from washbasins, drinking fountains, sinks, etc. come under this class.

All exposed surfaces of sanitaryware should be coated with an impervious, non-crazing vitreous glaze finish to make it impervious. Well known makes of sanitary appliances and fittings must be used in buildings as otherwise they tend to crack and become unusable within a short time.

27.13 STONEWARE PIPES AND FITTINGS

Salt glazed stoneware pipes are used for underground drainage from ancient times. These pipes are made from selected clay. The clay is first ground to a fine powder and just enough water is added to make it mouldable. It is then formed into pipes by high pressure extrusion. They are fired and salt glazed which make them dense and impermeable. They are cheap and durable so that they are very popular for use as drainage pipes for lowcost housing. However, plastic pipes are replacing these pipes in modern building practice because of ease in placing plastic pipes. Compared to plastic pipes, stoneware pipes are much cheaper in cost.

SUMMARY

Clay is used in building constructions in many forms. Clay consists of minerals and depending on the parent rock and climatic conditions of weathering, many types of clays are available in various parts of the country. By adding other materials and heating clay to different temperatures, different products can be obtained. It can also be made attractive by different types of glazing. Thus, ceramic products of many forms and types are used in construction of buildings. They are used in floors, walls, roofs as sanitary appliances and even for decoration of buildings.

REVIEW QUESTIONS

1. What is meant by the term "tile"? What are the characteristics of good floor tiles, wall tiles and roof tiles?

2. What is the difference between glazed and vitrified floor tiles used in building construction? Give a short account of the available types of ceramic floor tiles and indicate how you will choose a ceramic floor tile for a middle class residence?
3. What a short account of the process called glazing? What are the considerations in choosing glazed tiles for a building?
4. Explain the following terms:
   (a) Earthernware
   (b) Stoneware
   (c) Terracotta
   (d) Porcelain
5. What are Mangalore tiles? What are the tests to be done to check whether or not the quality of Mangalore tiles supplied is good.
6. Illustrate by rough sketches the shape of Mangalore tiles, country tiles and Allahabad tiles.
7. Write short notes on the following:
   (a) Clay floor tiles
   (b) Mangalore tiles
   (c) Ceiling tiles
   (d) Terracing tiles.

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[2] IS 651–1992: *Salt-glazed Stoneware Pipes and Fittings Specification.*

[3] IS 771–1979: *Specification for Glazed Fire-clay Sanitary Appliances (Part 1. General Requirements, Parts 2 to 6 Specific Requirements for Kitchen and Laboratory Sinks and other Items).*

[4] IS 654–1992: *Clay Roofing Tiles—Mangalore Pattern Specification.*

[5] IS 2556 (Parts 1 to 17): *Specification for Vitreous Sonitary Appliances* (General requirements, water dosets. squalting pons, washbasins, etc.)

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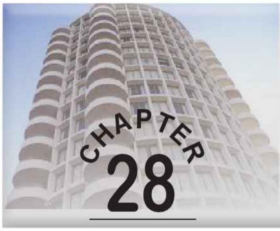


CHAPTER 28

Asbestos and Asbestos-Cement

28.1 INTRODUCTION

Asbestos occurs in nature as a fibrous mineral. It is made of hydrous silicates of calcium and magnesium. The natural fibre can be divided into two groups—those which are readily subjected to acid attack and those which are acid-resistant. The first group consists mainly of *chrysolite asbestos* which is allowed to be used only for industrial purposes. The second group comprises asbestos like *Amosite asbestos and Crocidolite (Blue) asbestos*. The second group is not allowed nowadays for use as they are said be related to diseases of the lungs like Lung career and Mesothelioma if the fibers get into the human system. Even though the Indian industry nowadays uses only Chrysolite asbestos for industrial purposes, it is considered advisable to use asbestos cement products with caution and sufficient care. In same countries the use of asbestos is not allowed in buildings. Asbestos fiber mixed with cement is asbestos cement. It is in this form that asbestos is mostly used in building industry. In this chapter we will briefly examine the general use of asbestos in building construction. Discussions about asbestos roofing sheets will be taken up in Chapter 32.

28.2 PROPERTIES OF ASBESTOS

The important properties of asbestos are the following:

1. It is fire-resistant. Its melting point is 1200 to 1500°C.
2. It is incombustible. It acts as a good insulator for heat.
3. It is rust free.
4. Its specific gravity is 3.10. (Comparable to that of cement = 3.15)
5. It has high tensile strength along the fibre.
6. It has good adhesion with cement so that the fibre can be used as a fibre reinforcement with cement.
7. It is a non-conductor. It acts as a good insulator for electricity.

28.3 USES OF ASBESTOS

The following are some of the uses of asbestos

1. It is mixed with cement to prepare asbestos sheets, asbestos pipes (rainwater pipes). etc. in buildings. These are much cheaper than plastic pipes.
2. It is mixed with bitumen to prepare felts for use as damp-proof course.
3. It is used to form asbestos paint.
4. As a heat insulator it is used for hot water pipes, boilers, furnaces, fireproof cloth, ropes, etc.
5. As an electric insulator is used for lining fuse boxes, switch box, covering for magnetic coils, etc.
6. It is mixed with other material to be used as brake linings for automobiles and such uses.

28.4 HARMFUL EFFECT OF ASBESTOS

The cause of the trouble of breathing in of asbestos fibre is that it gets lodged in the lungs and the fibre remains as a foreign body in the lung for a long time after the exposure. Even though *blue asbestos* is known for its very injurious effects in humans, it is now claimed that the effect of *chrysolite asbestos* on humans is very little. As chrysolite fibre is readily subjected to acid attack, it is claimed by the asbestos industry, that it gets cleared rapidly from the lungs with a half time of only 16 days. In contrast blue asbestos has a half time of 500 days (and cellulose fibre is said to have a half life of 1000 days). The Indian Industry mostly uses the chrysolite asbestos and the dust level in the factories is strictly controlled to less than 5 fibres/c.c exposure, for the safety of the workers. Under these circumstances the manufacture and use of asbestos is not still forbidden in India. In any case it is advisable to take precautions against fibre inhalation, when workers are engaged in asbestos work, in its manufacture, fabrication or replacement. In many cases a coat of white paint is recommended to be applied to the underside of the asbestos sheets as a protection against dispersal of fibre when asbestos sheets are used in residences. In spite of all its defects asbestos sheets still remain as one of the cheap building material in the underdeveloped and developing countries for buildings, for housing, factories, assembly halls, etc. Asbestos is used in pipes and other items also.

28.5 ASBESTOS CEMENT PRODUCTS

Asbestos cement is made of Portland cement with 15% asbestos fibres. The principal products made are AC sheets and AC pipes.

28.5.1 Asbestos Cement Roofing Sheets (AC Sheets) and Accessories for Roofing

These sheets come in three types namely (a) Corrugated sheets (two types) and (b) Semi-corrugated or tile profile sheets. These are covered by IS 459-1970. They are produced in the standard length of 1 to 3 m and "laid width" of 1.05 m. The thickness of the sheet can be 6 mm or 7 mm. The corrugated sheet has two variations—one in which the corrugations are 5.5 cm deep called the *deep corrugated sheets* and the other in which the corrugations are 2.5 cm deep called the *standard corrugated sheets*. For the *semi-corrugated or tile profile* sheets, the depth of corrugation is 5 cm. These are dealt with in more detail in Section 32.1 and Figure 32.1. In addition to sheets, many accessories like ridge pieces of adjustable type (serrated and unserrated) and apron pieces, eves filler pieces, etc. are also available for roofing.

28.5.2 Pipes and Gutters for Drainage

Waste and ventilating pipes and fittings for carrying soil waste are also produced by the asbestos industry. AC products are also used for rainwater gutters and rain water pipes, etc. which are necessary for drainage of rain water. They are covered by IS 1626-(1960). However as plastic pipes do not break easily and are more durable than these AC pipes they are being used more and more by the building industry. AC pipes are still popular in India simply because these AC pipes are very much cheaper than similar PVC pipes. When we think of low cost housing, asbestos products win over others.

SUMMARY

Asbestos and asbestos cement are used in the building industry roofs, pipes, etc. Even though their use is discouraged in developed countries, chrysolite asbestos roofs are still being extensively used in under developed and developing countries as an economical material for roofing. Plastic materials are replacing asbestos for roofs, pipes, etc. in building construction in developed countries.

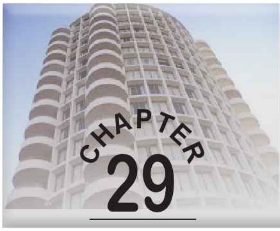
REVIEW QUESTIONS

1. What are the two groups of asbestos that occur in nature and which type is used in building industry?
2. What is asbestos cement? What are its uses in building construction?
3. What are the different types of AC roofing sheets available in the market? Give rough sketches of their profiles.

REFERENCES

[1] IS 459–1992: *Corrugated and Semi-Corrugated Asbestos Cement Sheets—Specification.*

[2] IS 1626–1991: *Specification for Asbestos-cement Building Pipes, and Pipe Fittings Gutters and Gutter Fittings and Roof Fittings (Part 1, Pipe and Pipe-fittings; Part 2, Gutter and Gutter Fittings; Part 3, Roof accessories.)*



Geosynthetics

29.1 INTRODUCTION

Geofabrics are also called geosynthetics or geotextiles. These are synthetic fabrics which are sufficiently durable to last a good length of time in soil environment (buried in soil) used in geotechnical engineering. Commonly used materials are polyester, nylon, polyethylene and polypropylene. The fabric may be woven, or knitted or punched. They are used for the following functions as shown in Figure 29.1.

1. Drainage paths for water for soil consolidation
2. Separation of different types of soil materials
3. Soil reinforcement in reinforced earth construction
4. Filtration of water from soil

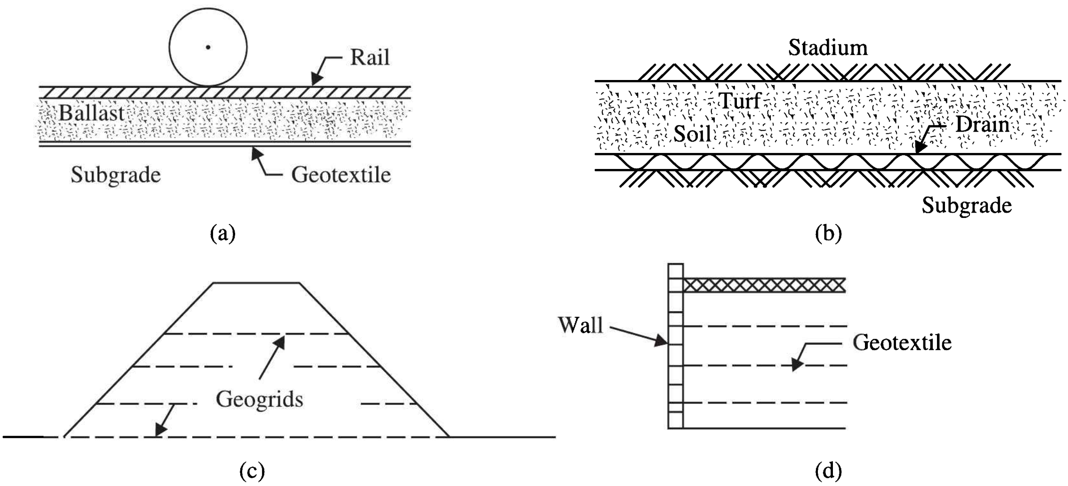


Figure 29.1 Use of Geotextiles (a) For separation (b) For separation and drainage (c) As reinforcement for bridge embankments (d) As reinforcement for retaining walls.

Geosynthetics are ideal for use in soil, as they do not deteriorate by corrosion in the presence of chemicals. They last for *a long time* when not exposed to direct sunlight and they are also not affected by water. They are extensively used these days especially for Mechanically

Stabilized Earth (MSE) also called Reinforced Earth Construction. In this chapter, we will briefly deal with the use of this material in building construction.

Note: Woven jute fabric treated with admixture of minimum 20% bitumen and suitable rot proofing agent is termed as rot proofed jute geotextiles. These are available in India and are used for various purposes. See References 5 and 6.

29.2 USES IN CIVIL ENGINEERING

The four fold uses of geotextiles in geotechnical engineering can be described as follows. In many practical cases, it may combine more than one of these functions.

1. ***As drainage paths to assist consolidation.*** As described in geomembranes in Section 29.3 item 4, geotextiles are used as drainage wicks to assist drainage and consolidation of clayey deposits. The modern ready made "plastic geotextile drain" consists of a plastic drain core and a geotextile jacket covering the plastic core pipe. They are efficient for soil drainage to assist in preloading of foundations.
2. ***As a separation medium.*** It can be used in many places, such as under railway track, to separate the ballast from subgrade, thus decreasing penetration of ballast into the weak subgrade.
3. ***As soil reinforcement.*** These reinforcements are used in the reinforced-earth techniques for the following purposes
   (a) For retaining walls and stability of slopes
   (b) For improving the bearing capacity of foundations (These reinforcements are more often used for improvement of foundations under conduits, ground subsidence, etc. than for foundation of buildings.)
4. ***As a filtration medium for drainage.*** In many situations, when used for drainage and separation, it also acts as a filter.

Table 29.1 gives the use of geosynthetics in some of the civil engineering works.

Table 29.1 Uses of Geosynthetics

No.	Application	Reinforcement	Drainage	Filtration	Separation
1.	Earth slopes	+	–	–	–
2.	Road work	+	–	–	+
3.	Drainage	–	+	–	–
4.	Wet fills	–	+	+	–
5.	River and coastal protection	–	+	+	+
6.	Land reclamation	–	+	–	–

29.3 CLASSIFICATION OF GEOSYNTHETICS

Geosynthetics have been classified into the following four groups:

1. ***Geotextiles (fabrics).*** These materials consist of either woven or non-woven fabrics (with small holes) and are generally used for separation, drainage, filtration and

reinforcement. From strength considerations, the strongest of these are the woven fabrics, then the resin bonded, melt bonded and finally the needle punched fabrics.

2. ***Geogrids.*** They have large openings and are made of materials with high tensile strength, low elongation and dimensional stability. They are made from plain polymer sheets by punching holes in it followed by two stretching operations so that a grid is formed as shown in Figure 29.2. They can be designed to have different strengths or the same strength in the two directions. They are mainly used for soil reinforcement or for separation of materials or for improving bearing capacity of soil.

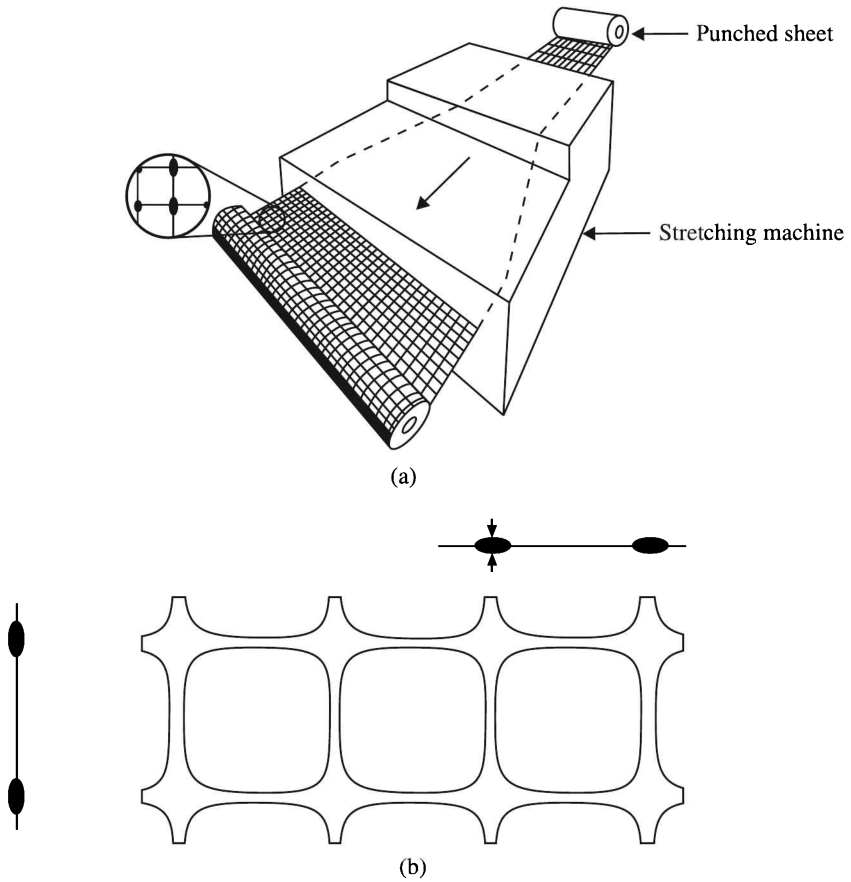


Figure 29.2 **Manufacture of geogrids (a) Stretching in machine (b) Final product as geogrid.**

3. ***Geomembranes.*** These materials are available in wide range of permeability. Continuous geomembrane barriers of sufficiently low permeability can be used to control fluid migration in geotechnical engineering while those of high permeability are used for drainage. For example, wick drains (used for drainage of soil to assist consolidation) refered to in Section 29.2 consist of grooved plastic or paper core covered by a plastic membrane. They are used to produce a wick ranging from 100 to 300 mm wide and

4 to 6 mm thick of any required length. The membrane-cover gives a permeable soil barrier to reduce core clogging and the core allows easy flow of water for drainage.

4. ***Linear strips for soil reinforcement.*** Polymer fibres are made into strips which can be used for reinforced earth in retaining walls. Glass-reinforced plastics are also considered as suitable for soil reinforcement (refer Section 24.8).

29.3.1 Properties of Geotextiles

The properties to be specified for the geotextiles to be used for a given work are the following:

1. Physical properties
   (a) Mass per unit area
   (b) Pore size
   (c) Surface finish
2. Mechanical properties
   (a) Load deformation characteristics
   (b) Long-term deflection characteristics
3. Hydraulic properties
   (a) Permeability
   (b) Long-term durability in soil

29.4 STRENGTH OF GEOTEXTILES FOR SOIL REINFORCEMENT

Table 29.2 gives a comparison of the different materials used for soil reinforcement.

Table 29.2 Comparison of Materials used for Linear Strip Soil Reinforcement

No.	Material	Tensile strength (N/mm^2)	Permissible tension (N/mm^2)	Percentage extension at working load (%)
1.	Galvanized steel tension strips	340	120	0.06
2.	Stainless steel	540	220	0.11
3.	GRP (Glass-reinforced plastics)	354	80	0.20
4.	Polymer fibre	10–100	Allow F.S. = 6	1.80

Note: The coefficients of friction of geogrids are considered as good and can be taken as much as equal to 0.70. When strips are embedded in soil, this friction acts on both sides of the strip.

29.5 USE IN EMBANKMENTS

As the embankments for flyovers in cities should occupy as little width as possible, the use of geotextiles as soil reinforcement for these embankments comes in very handy. Much steeper slopes than normally admissible with *earth only* can be provided by using soil reinforcement in the embankment as shown in Figure 29.1. Similarly, consolidation of foundations of many new railway embankments for Indian Railways has been carried out by using plastic geotextile drains (P.G. drains) instead of the old fashioned sand or wick drains.

SUMMARY

Application of geotextile in geotechnical engineering is a fast developing subject. They are nowadays readily available in India as some Indian companies have started manufacturing various types of geotextiles. They are being widely used in India.

REVIEW QUESTIONS

1. What are geosynthetics? What are its uses in geotechnical engineering?
2. How are geosynthetics classified? Explain their use in geotechnical engineering. Why are they prefered over metallic materials?
3. How can the slopes of embankments be reduced by using geotextiles as reinforcement?
4. List the important properties of geotextiles that should be examined before we select them for use.

REFERENCES

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[2] IS 1963 (1981): *Methods of Determination of Threads per Unit Length in Woven Fabric* (2nd revision).

[3] IS 1969 (1985): *Method for Determination of Breaking Strength and Elongation of Woven Textile Fabrics.*

[4] IS 1954 (1990): *Determination of Length and Width of woven fabric Methods.*

[5] IS 14715–2000: *Woven Jute Geotextiles—Specification.*

[6] IS 14986–2001: *Guidelines for Application of Jute Geotextile for Rain-water Erosion Control in Road and Railway Embankments and Hillslopes.*

CHAPTER 30

Materials for Waterproofing and Damp-Proofing

30.1 INTRODUCTION

Waterproofing of a surface is the treatment of the surface to prevent the passage of water like rainwater or groundwater from one side of a structure to the other under normal or hydrostatic pressure whereas *damp-proofing* is the treatment of a surface to stop the rise of water by capillary action. Thus, we make the foundation of a wall damp-proof by DPC whereas we make the reinforced concrete roof of a building waterproof for leakage due to accumulation of rainwater on top of the roof. Similarly, we make the basements waterproof so that the groundwater does not penetrate into the walls and enter the basement. The same materials are used for damp-proofing and waterproofing. Only the construction procedures are different. Waterproofing buildings is an important subject in building construction. There are a number of construction features to be provided for waterproofing of a building. In this chapter, we will deal only with the materials used in waterproofing. The methods involved are dealt with under building construction. We will first study the materials used for water proofing and then review broadly the following items of works.

1. Damp-proofing of foundations
2. Tanking of basements
3. Damp-proofing of walls
4. Waterproofing of wet areas
5. Waterproofing of roofs

30.2 WATERPROOFING OF CEMENT WORKS

As cement products like concrete and plaster are the most common materials to be made waterproof, we will deal mainly with waterproofing of cement products in buildings. The same principles can be applied to other materials like brick blocks, etc. Waterproofing of major works like tunnels are beyond the scope of this book.

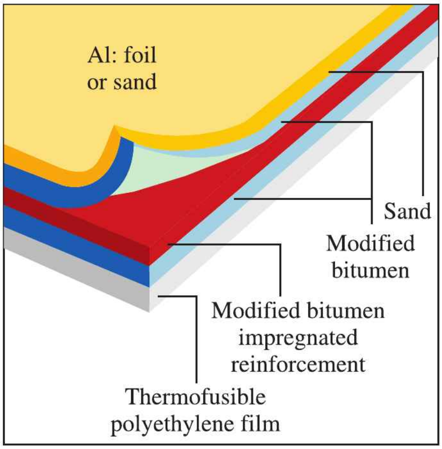
30.3 WATER PROOFING MATERIALS AND SYSTEMS

We may classify the *various systems* of water proofing as applied to buildings into the following categories:

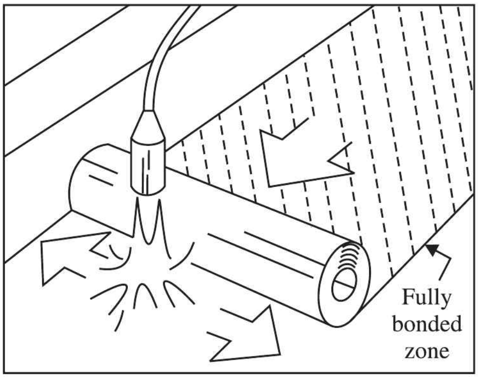
1. Waterproofing with bitumen membranes (plastomeric systems).
2. Waterproofing with elastomeric paints.
3. Waterproofing with epoxy formulations.
4. Integral waterproofing of cement plaster and concrete.
5. Waterproofing by slurry coats by capillary and crystallization systems.

30.3.1 Waterproofing with Bituminous Sheets (Plastomeric System)

Many types of bituminous sheets are used for waterproofing works. In India, factory-made bituminous sheets were formerly made with hessian base introduced under the trade name "tarfelt." Thus, older makes of "tarfelts" were made by impregnating vegetable or animal fibre mat (obtained in rolls) with bitumen to form impermeable sheets. These sheets were then stuck to roof surface by means of hot bitumen applied to the roof at the site. However, these vegetable and animal fibres tend to hold moisture and cause blistering (bubble like formations) due to vaporization of moisture from underneath. Hence, nowadays, the fibres have been completely replaced by sheets made of inorganic materials like fibreglass and plastics. (Fibreglass bitumen felt is covered by IS 719-1974.) The manufacture and installation of bituminous sheets is shown in Figure 30.1.



(a)



(b)

Figure 30.1 **Manufacture and installation of bituminous sheets for waterproofing: (a) Modern waterproofing membrane with modified bitumen. (b) Bonding of waterproofing membrane to separate roof by torching.**

At present, two types of plastic-based bitumen sheets are available in the market—one, like the traditional felt, which is to be stuck to the surface to be waterproofed with hot blown asphalt and the other designed so that the underside of the sheet is a thermofusible film which can be heated by a gas flame torch and then stick to the hot surface. The latter is more popular nowadays than the former.

This bituminous system is called the *plastomeric system*. One of the major disadvantages of this system is the problem of renewal. Most of these membranes last only five to six years.

It requires extensive surface preparation like removal of old treatment for their renewal and reinstallation at later stage.

30.3.2 Waterproofing by Elastomeric Paints

A large number of ready-to-use cold applied elastic (elastomeric) membrane-forming compounds are, nowadays, available for waterproofing. These compounds are special paints and their elastomeric feature distinguish them from ordinary paints. The requirement of such paints is their flexibility or elasticity which must not be lost over a large temperature range and time. These coatings are normally applied in film thickness of 0.5 to 0.75 mm using a roller, spray or brush. This thickness is approximately ten times thicker than of traditional paints. There are basically five types of these paints as follows:

1. Acrylic-based
2. Polyurethane-based
3. Hypalon-based
4. Polyvinyl acetate copolymer-based
5. Polymerized elastomeric bitumen, penetrating oils and other admixtures

Of these, acrylic coatings are the most popular. Most of these paints are now manufactured in India and are available freely. It is also possible to introduce very fine fiber glass mats as reinforcement along with these paints which will enhance the crack-bridging capacity of these paints.

30.3.3 Waterproofing with Epoxy Formulations

Epoxy materials (the two-phase system of araldite and hardener with or without filling materials) are also used for structural repairing of concrete as well as waterproofing of terraces, toilet slabs, etc. (refer Sections 24.7.9 and 26.2.3). Two coats of epoxy mix consisting of Araldite GY257 and Hardener HY840 in equal proportions by weight are found to give good results as a waterproofing material.

30.3.4 Integral Waterproofing

Concrete having cement content of over 300 kg/m^3 (as in 1:2:4 mix) and water-cement ratio between 0.4 and 0.5 gives a very good impermeable concrete. In order to improve placeability with the above water-cement ratio, plasticizers or superplasticizers can be added. Other cheaper chemicals called integral waterproofing compounds (for example Cico) are available in powder or liquid form (refer Section 14.3.5). They are added to cement mortar or cement concrete during the time of mixing at the rate of 1 kg per bag of cement. Their main action is to improve workability with reduction in required quantity of water for placement. This water reduction reduces the permeability of concrete.

Another additives that can be added to make concrete impermeable are *latex-based polymers* (refer Sections 14.3.7 and 23.6). They are added to cement mortar or concrete to make polymer product. It is claimed that during the process of hydration of cement coupled with polymerization of latex-based polymers, the pores in the mortar or concrete get coated with latex film which retards the capillary action of water. Latex-based cement mortar can be used for plastering of inside of small water tanks in residential buildings to reduce leakage.

30.3.5 Waterproofing by Slurry Coats

The Danish chemist Lauritz Jensen developed cementitious crystalline waterproofing compounds in 1942. It contains Portland cement and quartz or silica sand which functions as a carrier for a *propriety compound of active chemicals*. The chemicals are assumed to penetrate the capillary cavities in the cement paste by osmotic pressure of water. Here they react with calcium hydroxide and the capillary water to form insoluble crystalline complexes. These crystals block the capillary cavities preventing the passage of water but still allowing the vapour to escape. We must be aware that as it lets concrete "breathe", *it cannot act as a vapour barrier.* These chemicals, thus once penetrated into the pores, become an integral part of concrete. In the absence of water, they lie dormant but becomes active in the presence of moisture or when water comes into contact with the concrete.

It is claimed that unlike other waterproofing compounds, these materials are effective even if they are applied on the *negative side* of the structure to be waterproofed. In most of the cases, it may have to be pressure grouted, if it is applied from the negative side, to completely prevent leakage. (The side where water acts is called positive side and the dry side is called the negative side. Most of the waterproofing materials are applied on the positive side.)

30.4 DAMP-PROOF COURSE (DPC)

Damp-proofing of foundation is necessary to prevent capillary rise of water in the wall and also in ground floor. It is carried out as shown in Figure 30.2.

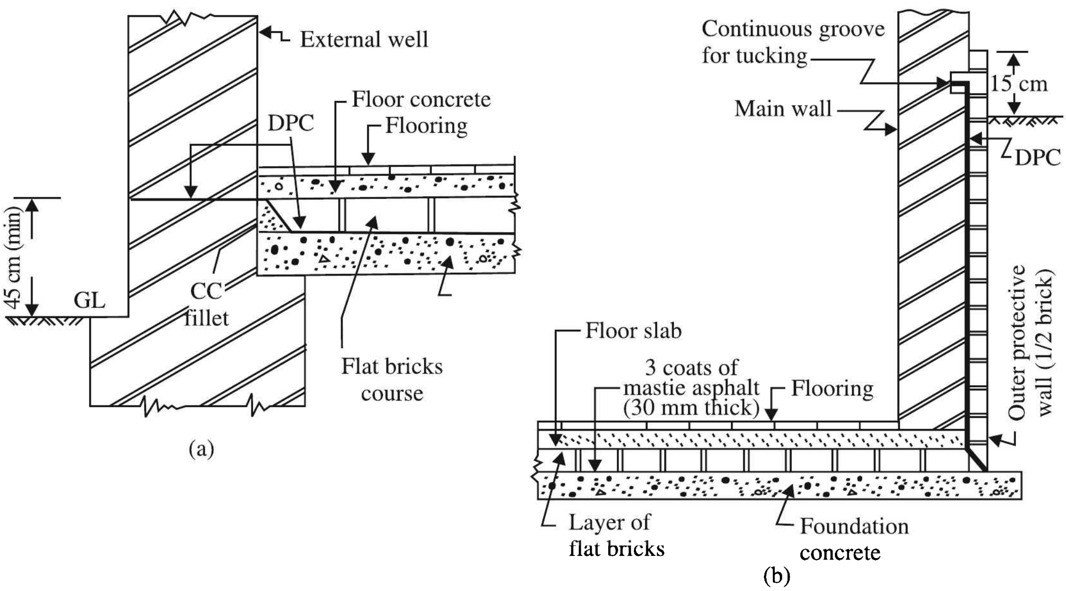


Figure 30.2 Damp-proofing for floors and tanking for basement: (a) DFC for flooring with high groundwater level (b) External asphalt tanking for basement.

The following materials are commonly used for damp-proofing:

1. Flexible materials like hot bitumen, bituminous felts, plastic sheet, metal sheet of lead, copper, etc.
2. Semi-rigid materials like mastic asphalt and other combination of impervious materials
3. Rigid materials like impervious bricks, stones, slates, cement mortar or cement concrete painted with bitumen, etc.
4. Stones
5. Mortar with waterproofing compounds
6. Cement concrete with waterproofing compounds
7. Coarse sand layer under floors
8. Continuous plastic sheets under floors

The aim of the construction is to provide an impermeable barrier so that the capillary action is destroyed. For flooring of ground floor with no high groundwater level, a thick bed of coarse sand under the floor can serve as damp-proofing material. DPC is placed only under the wall. This is a convenient method as it is mandatory that the ground floor level should be at least 15 cm above the general ground level. Where the groundwater level is high as shown in Figure 30.2(a), a DPC becomes necessary.

30.5 TANKING OF BASEMENTS

The waterproofing construction for preventing water from the soil outside the basement to seep into the inside of the basement is called *tanking*. It is also called basement waterproofing. The most popular material used for this work is *mastic asphalt* and other types of bituminous materials. External tanking is shown in Figure 30.2(b). When the asphalt layer is built inside and covered with brickwork, it is called internal tanking.

30.6 DAMP-PROOFING OF WALLS ABOVE GROUND LEVEL

Damp-proofing of walls is required against seepage of rainwater from outside to inside the building. It can be carried out by proper construction like cavity wall construction or by surface treatment of the walls. External waterproof paints or silicon water-repellent paints are usually used for water penetration through walls. (Silicon resins when applied on porous masonry can also prevent efflorescence by trapping all of the soluble salts within the masonry.)

30.7 WATERPROOFING OF WET AREAS

Sanitary areas like washing areas, bathrooms, toilets are called wet areas. Even, verandahs and balconies where rainwater can accumulate come under this category. These areas can be constantly wet. If water accumulates in the upper floors, as in a two or multistorey buildings, there is likelihood of penetration of water which affects the underside of the slab. Peeling of paint under the floor is common due to this wetness. In extreme cases, it can be so bad that water may drip down in droplets from these floors. The most efficient method is to attend to this at the construction stage itself by applying a bitumen coat or slurry coat in these areas on the positive side and then place the flooring on this treated area. Details of these construction will be studied in building construction.

30.8 WATERPROOFING OF ROOFS

Methods of waterproofing of roofs depend on the type of roofs and the details of construction. These methods are dealt with in Building Construction. For flat roofs, which require more protection than the slope roofs, the following four methods need special mention.

1. Lime concrete terracing for waterproofing of concrete roofs
2. Waterproofing with bituminous sheets
3. Waterproofing with elastomeric paints
4. By using waterproofing slurry on the roof and covering it with tiles

The second and third methods come under the category of membrane waterproofing of concrete. Details of these works are dealt with in Building Construction. However, as lime concrete terracing is very much used in construction of middle class houses, we deal with lime concrete in detail as a material.

30.9 PREPARATION OF LIME BRICKJELLY CONCRETE (LIME CONCRETE)

Lime concrete with or without tiles is the traditional waterproofing system for reinforced concrete roofs. The method of preparation of lime concrete can be briefly described as follows.

Lime concrete is prepared from broken brickbat aggregates and lime mortar. The lime mortar is *separately prepared by* mixing one part of slaked lime and two parts of surki by volume. (No sand is to be in this concrete.) They are thoroughly mixed with the required quantity of water. The mortar is thoroughly ground in a mortar mill or a mechanical grinder. This mortar is added to the aggregate in the ratio of 1:2½. The aggregates should be thoroughly soaked in water for a period of not less than six hours before lime mortar is added to it. (The addition of 12 kg of bar soap and 4 kg of alum in each cubic metre of lime concrete after dissolving it in water will improve the waterproofing capacity of lime concrete.) The resulting lime concrete should be used within 36 hours of preparation of the mortar if surki is also incorporated in the mixture. As it is commonly made with brick jelly as the coarse aggregate, it is also called lime brickjelly concrete.

During the laying of the concrete on the roof, by wooden thappies the surface should be sprinkled liberally with lime water and also a small portion of one of the following solutions.

1. A solution prepared by boiling 1.75 kg of Gur (jaggery) 1 kg of Bael fruit and 60 litres of water.
2. A solution made by soaking 60 g of "Kadukai" broken into small pieces, with 20 g of jaggery and 40 litres of water for 12 to 24 hours.

The lime brickjelly concrete should be cured for at least six days by covering it with a thin layer of straw and keeping it wet continuously. Over this layer of brickjelly concrete laid, one course of pressed clay tiles is usually provided to complete waterproofing roofs. The details of laying the concrete will be dealt with in building construction.

30.10 REFLECTIVE SURFACES FOR ROOFS

Black surfaces absorb heat from the sun and hence, light or white surfaces are prefered for roofs. For roofs with no traffic like sloping roofs, domes, etc., aluminium paint can be applied. Otherwise, an aluminium foil is incorporated in the product itself as shown in Figure 30.1. In case of asphaltic roofs, it is customary to blend the surface with lightcoloured stone chips. Even ordinary white washing of the roof surface with lime in summer is claimed to reduce the inside temperature by few degrees.

SUMMARY

Damp-proofing and waterproofing are very important procedures in building construction. Their actual use in a building should depend on local practice. What is applicable to a “warm and humid zone” like Kerala is not suitable for a “hot and arid zone” like Rajasthan. Details of actual construction is to be studied under building construction. This chapter is only a review of the materials used in waterproofing and damp-proofing.

REVIEW QUESTIONS

1. What materials are used for the following purposes:
   (a) DPC
   (b) Water proofing roof of buildings with flat roofs.
   (c) Tanking

2. Write short notes on the following:
   (a) Plastomeric waterproofing materials
   (b) Elastomeric waterproofing materials

3. Enumerate the various types of waterproofing systems and their action.

4. Give a brief account of the materials used for waterproofing of concrete roofs and basements of buildings.

5. What materials would you use to repair the minor leaks in domestic underground water tank built with bricks and plastered with cement mortar.

6. What are wet areas of a building? How would you make it leak–proof.

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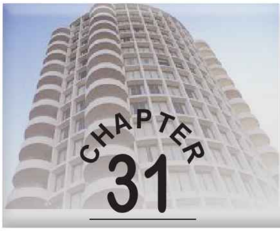


CHAPTER 31

Materials for Flooring

31.1 INTRODUCTION

A large number of alternative materials are, nowadays, available for construction of floors. Our choice for floor material will depend on many factors such as the use of the floor, the traffic expected, finance available, time available for construction. For example, floors for railway stations, dancing rooms and computer will be different from each other. Similarly, in many residences, ceramic tiles which require no polishing after laying are chosen for reducing the time of completion of the work. In this chapter, we will briefly deal with only the more commonly used materials. The details of construction of these floors will be dealt with in building construction. The commonly used floors are the following.

1. Brick on edge flooring
2. Cement concrete flooring (with and without granolithic concrete floor topping)
3. Cement concrete flooring with red oxide of iron
4. Cement concrete flooring with metallic topping
5. Clay tile flooring
6. Glazed ceramic tile flooring
7. Wooden flooring and wood block (parquet) flooring
8. Terrazo (marble chips) flooring (in situ and with tiles)
9. Marble flooring
10. Other stone flooring (kota stone, sand stone, granite, cuddappa slabs, etc.)
11. P.V.C. sheet (or tile) flooring. (Vinyl flooring)
12. Linoleum flooring
13. Rubber flooring
14. Cork flooring
15. Asphalt flooring

Note: The term "*Indian patent stone flooring*" simply refers to concrete floor with a base course of concrete on subgrade and a wearing course of concrete as floor finish. Laminated sand stone slabs are called Flag stones. Floors made by using these stone slabs an concrete are called as "*Flagstone flooring*".

Materials used for the first five types have been already covered under the various chapters of this book. In this chapter, we will deal briefly with the following materials:

1. Ceramic tiles (Glazed and vitrified tiles)
2. Terrazo flooring tiles
3. Stones for flooring
4. Resilient flooring materials

31.2 CERAMIC TILES

We have already discussed in Chapter 27 that there are many types of ceramic tiles that can be used for flooring. Firstly, we have the ordinary clay flooring tiles which have been traditionally used in many old buildings. These tiles are being replaced by glazed ceramic tiles (like Spartec tiles) which are made from special clay and given a coloured glazing. Glazed tiles were originally used only for walls where there is no traffic, but improved techniques of glazing, have made it possible first to manufacture these tiles for use in light as in residences traffic. Nowadays, they are also made for heavier traffic as in airports. As these tiles require very less time for laying as compared to terrazzo, it is popular for a number of places like residences. However, as ordinary ceramic tiles tend to have irregular edges, the joints between the tiles have to be large and are unsightly. Unless the glazing is of sufficient thickness glazed floor tiles, tend to wear away soon. They are also brittle and tends to crack if heavy objects fall on them. Hence, great care should be taken in their selection.

Further progress in ceramic tiles were made in the production of *fully-vitrified floor tiles*. These tiles are also available in different colours. They are generally available in 30 cm × 30 cm or 20 cm × 20 cm sizes ordinarily in thickness of 7.5 mm. They are also made in thickness of 10 mm for medium duty industrial floors and chemical resistant lining in factories. The tiles available in the trade name Granamite belong to this category. Polished vitrified floor tiles (like the trade name Mirror stone) are also available. They are claimed to be twice as tough as granite or marble. One of the advantages of these tiles and other ceramic tiles made of advanced techniques is that their edges are generally reground to perfect line after its manufacture so that the mortar joint can be made very thin as in terrazzo floors. The joints in vitrified tile flooring can be very much thinner than those in ordinary glazed ceramic tiles.

31.3 TERRAZO (MOSAIC) TILES

Terrazo as in situ and tile floors were once very popular in India and are still being used in middle class houses. However, unless the tiles are made of proper constituents and are well cured, they tend to get pitted. It also requires polishing after it is laid so that enough time should be given at the planning stage itself for its laying with respect to the time of completion of the building. Terrazo (popularly known as mosaic) is essentially a decorative concrete in which the aggregate *is white or coloured marble chips* and the binder is cement (grey white or coloured) and marble powder (or magnesite powder or very fine sand). It is also called Venetian mosaic as this type of work originally started in Venice where there was an abundance of marble chips available from marble works. In strict usage, the term "mosaic" refers only to works where marble chips (and also ceramics) are arranged in a regular pattern or picture. However, nowadays, we use this term loosely to terrazzo also where the chips are distributed at random. Terrazzo can be laid in situ or from factory-made precast tiles. However, the main disadvantage of such floors is the difficulty to get good raw materials and the time taken for polishing the surface. As these tiles are used extensively all over India especially in middle class homes, we will examine these tiles in more detail.

31.3.1 Materials for Terrazo Tiles

1. ***Aggregates (marble chips).*** Marble chips (white and coloured) are preferred for terrazzo works. Special aggregates composed of compact stone or minerals of agreeable colour like limestones, dolomite black cuddapah stone of *similar hardness as marble* can also be mixed to give attractive designs. *The hardness of the cement binder and the aggregates should match for an even wearing of the surface when used for flooring*. If very hard stones like quartzite are used, then the cement around it will wear, leaving the hard part in place resulting in a very rough and pitty surface with long use. The cause of failure of most of mosaic tiles in south India is the use of wrong chips for its manufacture. The requirement that the chips should have hardness only equal to that of marble is an important consideration in choosing mosaic tiles.

   Marble aggregates for terrazzo work are available in the market with the gradations shown in Table 31.1.

Table 31.1 Grades of Marble Chips

Grade number	Aggregate size (mm) (largest dimension)	Minimum thickness of terrazzo work using the specified size of aggregate (mm)	
		In situ	In tiles
00	1 to 2	6	See Note (3)
1	2 to 4	9	
2	4 to 7	9	
3	7 to 10	12	
4	10 to 13	*	
5	19 to 25	*	
6	25 to 32	*	
7	> 32	*	

Notes:

1. *For cast-in-place work, the thickness of topping depends on the sizes of aggregates used. For aggregate sizes larger than 10 mm, the thickness of topping should be preferably 1.5 times the size of the chips.
2. Very large chips are not used for precast tiles. They can be placed manually when cast-in-place method is used.
3. For precast tile work, the finished thickness of upper layer shall not be less than 5 mm for chips up to 6 mm and also for mixed chips ranging from the smallest to 12 mm. It is to be not less than 6 mm for mixed chips varying from the smallest to 20 mm.

2. ***Cement to be used.*** Portland cement may be grey, white or coloured. If coloured cement is obtained by mixing colouring oxides, it should be first mixed thoroughly in

a ball mill or roller mill to get uniform colour. Otherwise, readymade coloured cement should be used. The proportion of pigment should not exceed 10 per cent of the weight of cement.

3. ***Marble powder.*** Usually, white marble powder is used instead of sand. It gives a body to the cement. Magnesite powder and fine sand can also be used. The mixture usually consists of 3 parts of cement to 1 part of marble powder by weight.

31.3.2 Manufacture of Terrazo Tiles

1. ***Mix proportions.*** For every part of cement-marble powder mixture the proportion of aggregates by volume to be used is as in Table 31.2.

Table 31.2 Mix Proportions for Terrazo Work for In Situ Works

Size of aggregate	Proportion of aggregate to cement-marble powder mixure by volume
Grade 00,0 and 1	1.75:1
2 and 3	1.50:1
4 and 5	1.25:1
Mixed aggregate	1.50:1

Note: For precast work, the ratio of aggregate to cement mix is generally 1.1 to 1.

2. ***Mixing.*** First, the cement and marble powder are mixed thoroughly and then the marble chips are added to it. They are mixed to a homogeneous mix. The full quantity of dry mixture required for the whole work is prepared in one lot to ensure uniformity in colour and design of the terrazzo work. Smaller quantities are taken from this mixture and used. Water used for mixing should be just sufficient to make the mortar mix workable.

3. ***Structure of terrazo tiles.*** The tiles can be prepared through both the so-called dry process and wet process. The dry process is considered simpler than the wet process and is preferred by some manufacturers as it gives clear outlines in multicoloured tiles. These tiles have two layers—*the facing layer* of chips and cement mix and the *backing layer* of cement mortar. In the dry process, the tiles consist of one facing layer and one backing layer. In the wet process, they consist of one facing layer and two backing layers. The facing layer can be dry (4 to 7 per cent moisture content) or in a thick slurry like condition. The backing layer is made of cement and sand or cement brickjelly mix in the ratio 1:3. The moisture of this mix is about 10 to 18 per cent only. When the tile is composed of three layers, the middle layer is drier than the bottom layer.

4. ***Pressing of terrazo tiles.*** The two layer tiles are made as follows. A hydraulic press which can exert a pressure over 140 kg/cm^2 is needed for the manufacturing. The mixes for the facing and backing layers are prepared and stored in compartments near the work table on both sides of the hydraulic press. A steel mould fitted with a removable bottom plate is filled first *with the facing mix* by means of a ladle to the specified

depth (say 6 mm or 1/4 inch). Over the above layer, the moist *backing mixture* is spread to the overall thickness required. The mould is covered by a top plate and the mixture is subjected to a pressure of about 140 kg/cm^2. (Generally, the mixture gets compressed to the required thickness. After withdrawing from the press, the tile with the base plate is removed from the mould and the tiles are stacked in a wooden rack which can accommodate 12 to 18 tiles standing on their edges. The tiles are allowed to remain on the rack for aircuring for 8 to 12 hours. Then, the racks are submerged in a tank (6 m × 3 m × 1.2 m) for about 48 hours. It is then stored in a curing shed (with water spraying) *for at least two weeks*. They are removed and ground in a polishing machine (first polishing) before delivery to the construction site. The most important defect found in tiles is "crazing" which is shown by cracks on the surface or sides. The cause of this defect is differential shrinkage between the layers of the tiles and the remedy lies in giving proper attention to curing especially during early days of the manufacturing. Tiles used for laying on the floor should be properly cured to avoid shrinkage of tiles and consequent opening up of joints in the floor.

5. ***Sizes of terrazo tiles.*** Terrazo tiles should conform to IS 1237-1959. The *nominal sizes* (together with the joints) are as follows:
   (a) 200 mm × 200 mm with 20 mm total thickness
   (b) 300 mm × 300 mm with 25 mm total thickness
   (c) 250 mm × 250 mm with 22 mm total thickness

31.3.3 Test Requirement of Precast Cement-Concrete Terrazo Tiles

Usually the following four tests are prescribed for testing the quality of mosaic tiles:

1. Absorption test
2. Abrasion test (resistance to wear)
3. Transverse strength test on dry tiles
4. Transverse strength test on tiles after immersion in water for 24 hours

For each of the above tests, six samples are to be tested for every 2000 tiles or part thereof.

1. ***Absorption test.*** Full-sized tiles are immersed in water and the absorption of water is to be determined as a percentage absorption.
2. ***Abrasion test.*** This test is to be carried out in a laboratory with a machine described in Appendix A of IS 1237-1959 titled "Cement concrete flooring tiles". The abrasive powder (with an aluminium oxide content not less than 95 per cent by weight) of Moh's scale 9 is used for the test. The test is conducted on a 7.06 cm × 7.06 cm (50 sq. cm) specimen cut from the tile. After it is abraded in the machine by 200 revolutions in the prescribed manner, the loss in weight is determined. The wear in thickness is calculated by weighing the tiles before and after the test as follows:

$$t = \frac{(W_1 - W_2)V_1}{W_1 A}(10) \text{ mm}$$

$$\text{as } t\, A \frac{W_1}{V_1} = W_1 - W_2$$

where

t = average loss of thickness in mm
W_1 = initial weight in gm of specimen
W_2 = final weight in gm of specimen
V_1 = initial volume in c.c. of specimen (by loss in weight in water).
A = surface area in sq. cm of the specimen.

Note: The worn surface should also be examined for uniformity of wearing and pitting. (With very strong chips like quartzite, there will be pitting.)

3. ***Transverse strength in dry and soaked specimen.*** In this test, full-size tiles are tested on a span indicated in Table 31.3 and loaded at midpoint. The modulus of rupture should not be less than 3 N/mm^2 for dry specimen and loss in modulus of rupture should not be more than one third in specimen tested after 24 hours of submersion in water. They are tested with wearing surface as the upper surface.

Table 31.3 Strength Test of Terrazo Tiles

Actual size of tile (cm)	Span (cm)	Breaking load (kg)	
		Dry test	Wet test
19.85 × 19.85	15	106	71
24.85 × 24.85	20	120	80
29.85 × 29.85	25	149	99

31.3.4 Terrazo Laid In Situ

In situ terrazzo flooring is laid over as a thin layer over concrete topping. The materials used for the topping are the same as that used for terrazo tiles. The procedure of laying the in situ floor will be studied under building construction.

31.4 STONE FLOORING

Stone floors are very attractive and are commonly used in places of heavy traffic like commercial, institutional and public buildings. They are also known by the following names:

Flat stones used for paving are known as flagstones. Such floors are known as flat stone floors. The name "Indian patent stone flooring" is used for concrete floors and the term grey artificial patent stone floors is sometimes used in PWD specifications for concrete floors).

Some of the natural stones used in India for flooring are the following:

(a) Cuddappa slabs
(b) Kota stone
(c) Sand stone
(d) Shahabad stone
(e) Granite
(f) Marble

The standard sizes of stones used are 30 cm × 30 cm, 60 cm × 60 cm and 45 cm × 60 cm with thickness 2 to 4 cm. The top surfaces of all these stone floors can be polished. They wear very well under heavy traffic depending on the hardness of the stone and look very attractive in their appearance. Of all the stone floors, marble floors are considered as the most superior floor and we will examine these floors a little more in detail.

31.4.1 Marble Stone Flooring

There are different types of marbles available in India. CPWD specification 77 gives a list of various white and coloured marbles available in India in its Chapter 8 entitled "Marble Work". Marble is a metamorphic rock like slate, schist, etc. It has a specific gravity of 2.65 and a crushing strength of about 70 N/mm^2 (much above ordinary concrete). In textural classification, metamorphic rock is classified as "granular", fine or coarse grained. It can have streaks of other materials in it. The quality of the stone too is based on its texture and appearance. The following are the common types of marbles available in India:

1. Plain white marble like *Makrana white* and *Abu white*
2. *Abu panther* marble (white marble with blue and black spots)
3. White veined marble like Adanga marble
4. Black marble
5. Black zebra marble with grey and white veins
6. Green marble
7. Pink plain marble with light and dark shades
8. Grey marble
9. Brown marble

In each of these marbles, there are different varieties named after the places of their origin. Makrana marbles were considered as of the best quality but due to excessive mining, it is more or less extinct at present. Extreme care should be taken in choosing marble for large marble work. It is very difficult to get marble of uniformly good quality in large quantities. The following are the important properties to be considered:

1. ***Sizes.*** The standard sizes of blocks, slabs and tiles of marble are shown in Table 31.4.

Table 31.4 Sizes of Marble (centimetres)

Type	Length (cm)	Breadth (cm)	Thickness (cm)
Blocks	30 to 250	30 to 100	15 to 100
Slabs	70–250	30–100	2–15
Tiles	10–60	10–60	1.8–2.4

Note: Lengths and widths will be in multiples of 10 cm and thickness in multiples of 1 cm. Tiles are usually square in multiples of 10 cm.

2. ***Physical properties of good marble.*** A good marble should have the following physical properties:

(a) Moisture absorption after immersion in water for 24 hours should not be more than 0.4 per cent by weight.

(b) Its hardness on Moh's scale should be at least three (see Section 1.11.1).

(c) Its specific gravity should not be less than 2.5.

Note: A good marble is to be recognized by its appearance rather than these test results.

One of the principal defects of many crystalline varities of white marble is their porosity. It oil, ink, etc. fall on the surface, it is drawn into the pores so that it becomes difficult to remove these discolourations.

31.5 RESILIENT FLOOR MATERIALS

The word "resilient" means able to bring back to the original form after compression or stretching. Floors such as rubber floors, linoleum floors, PVC floors are called resilient floors. Such floors are used in places where we want to reduce noise to the minimum level as in libraries, computer rooms, office rooms, etc. and also where we want electrically-insulated floors. We will deal with them briefly in the following sections.

31.5.1 Rubber Flooring (IS 809–1970)

Specially-prepared rubber sheets are supplied in the following sizes:

1. Rubber sheets 90 cm wide and 2.5, 3.5 and 5 m long
2. Rubber tiles 20 cm × 20 cm (3.2 mm thick), 30 cm × 30 cm (4.8 mm thick); 45 cm × 45 cm (6.4 m thick)

The market form of these tiles and sheets may be (1) plain or marbled (2) ribbed or fluted (3) with fabric backing or fabric inset (4) with sponge rubber backing (5) with plain rubber packing as needed (refer CPWD specifications 77 for details). The rubber sheets are expensive in initial cost and spilling of oil, grease and gasoline, etc. can spoil the floor. They are not used in situations exposed to direct sunlight or rain as they deteriorate quickly under these conditions.

31.5.2 Linoleum Flooring (IS 653–1962)

Linoleum is manufactured by mixing oxidized linseed oil with gum, resins, pigments, wood, corkdust and other filler materials. The material is usually supplied with a Hessian backing. The Hessian backing shall have not less then 43 ends and 33 shots per decimetre (according to CPWD specifications 77) and a peice 90 cm × 100 cm should weigh not less than 200 grams. It is supplied in width of 2 m to 4 m and thickness varying from 1.6 to 6.7 mm. (The thickness is to be measured by a micrometer exerting a pressure of 1.5 kg/cm^2 on the linoleum surface). The length of sheets supplied with thickness up to 6 mm is 5.5 m and higher thickness is usually supplied in 3 metres in length. They can be plain or printed with attractive patterns.

Linoleum can be laid on many types of surfaces like timber, concrete metal, etc. Its main disadvantage of these tiles is that it is subjected to rotting when kept wet. Hence, it is not recommended for basements, bathrooms, kitchens and so on. We should also note that linoleum is combustible and not free from fire hazards.

31.5.3 PVC Sheet and Tile Flooring (IS 3492–1966)

PVC flooring material is generally used for decorative purpose in residential and other places. It can be laid on concrete metal or timber. It should consists of thoroughly blended composition of thermoplastic, binders, fillers and pigments. The thermoplastic binder can be vinyl chloride or a copolymer of vinyl chloride. Polymeric material shall be compounded with suitable plasticizers and stabilizers. They can also be backed with hessian or woven fabric. The thickness for plain floor covering without backings vary from 1.5 to 40 mm and those with backings vary from 2.0 to 5.0 mm. They are supplied as sheets rolls and as tiles. The widths of sheets can be 1.0, 1.5 and 2 metres and the length of the roll is not less than 10 metres. (The thicknesses of these sheets are to be measured by a micrometer with a flat bearing surface of at least 6.5 mm diameter at both the contact points.) Since a burning matchstick or cigarette can damage the neat surface of the PVC sheet, good care should be taken in its maintenance.

31.6 SELECTION OF TYPE OF FLOOR

The type of material selected for flooring will depend on its use, expected traffic, the time taken to complete the work and cost. For places like railway platforms, where we need very hard wearing floors, usually dressed granite or other stone floors are recommended. In residences, even though mosaic floors were once used extensively, the time taken for laying and polishing has forced people to adopt ceramic and other tiles which can be used as soon as it is laid without further work. Accordingly, ready-made tile floors of all makes which do not require further work like polishing are becoming more and more popular nowadays. We must also take into consideration the place where the tiles are to be laid. Tiles suitable for the kitchen may not suit the tile for the drawing room. In any case, considerations should be given to the working life of each material while selecting these floors. As costs are escalating, repair of floors at later years will always prove to be very costly.

SUMMARY

Many types of flooring materials are available in the market. The material adopted should suit its use, should be economical and easy to maintain. Details of laying floors will be studied in building construction.

REVIEW QUESTIONS

1. (a) Give a list of five different types of popular flooring materials used in building construction.

(b) What are resilient floors? Give a short account of their usage.

2. What is terrazzo? Give a short account of the manufacture of terrazzo tiles.

3. What types of floors would you recommend for the following? Give reasons for your choice.

(a) Assembly hall of a college.
(b) Entrance lobby of high class hotel.
(c) Drawing room of a high class residence.
(d) Dancing hall.
(e) Factory floor.
(f) Bathroom.
(g) Computer room.
(h) Operation theatre.
(i) Chemical laboratory.
(j) Grain storage godown.

4. Write short notes on the following:

(a) Terrazzo and mosaic
(b) Marble floors
(c) Flagstone floors
(d) Indian patent stone flooring
(e) Resilient floors

5. What type of floors (give alternatives) would you recommend for the following. Give reasons.

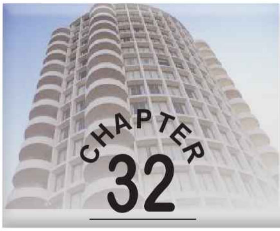
(a) A low cost house
(b) A middle class residence
(c) A high class residence
(d) Assembly hall of a school.

6. What are glazed tiles? What are the types available in the market and how will you select the type to be used?

7. What are differences in the requirements of floor tiles and wall tiles? In what places would you consider tiling the walls?

REFERENCES

[1] IS 3583–1988: *Specification for Paving Bricks.*
[2] IS 1237–1980: *Specification for Cement Concrete Flooring Tiles.*
[3] IS 809–1992: *Rubber Flooring Materials for General Purposes.*
[4] IS 653–1992: *Linoleum Sheets and Tiles—Specification.*
[5] IS 3462–1986: *Specification for Unbaked Flexible PVC Flooring.*



CHAPTER 32

Light Roofing Materials

32.1 INTRODUCTION

Roofs of buildings are usually of the following types.

1. Flat roofs or terraced roofs like concrete roofs, Madras terrace roofs, etc.
2. Pitched roofs which is further classified as lean to roof, gable roof, hip roof, etc.
3. Curved roofs like shell roofs

Flat roofs and shell roofs are, nowadays, made of reinforced concrete or bricks or a combination of both. On the other hand, a number of materials are available for covering pitched roofs. Even though tiles made of clay, (which we have already dealt with in previous chapters) are heavy, by tradition and architectural reasons even now tiles are extensively used in India depending on local conditions. In addition to these tiles, there are a large number of alternate light weight materials that are available for sloped roof. Among them, the commonly used materials are the following:

1. Asbestos cement sheets
2. Galvanized iron sheets
3. Corrugated aluminium sheets
4. PVC sheets
5. Other types of sheets

The principal advantage of these materials is their low weight. Thus, whereas clay tiles have a weight of 65 kg/m^2 the corrugated AC sheets have a weight of only 16 kg/m^2 and corrugated galvanized iron sheets have only 12 kg/m^2. Aluminium sheets are much lighter. We will briefly examine the characteristics of these light roof materials in the following sections.

32.2 ASBESTOS CEMENT SHEETS (IS 459–1992)

In Chapter 25, we have dealt with asbestos as a construction material. In this section, we will deal specifically with AC (Asbestos Cement) sheets. Even though the use of asbestos products is discouraged, these sheets are the cheapest permanent roof covering material available among the popular roof coverings. The brands of AC sheets available in India are given in Figure 32.1 and Table 32.1 and are the following:

1. *Deep corrugated sheets* are with 7½ corrugation with 1.05 m width and larger depth of corrugation of 55 mm. They are also called big six corrugated AC sheets.
2. Standard corrugated sheets with 10½ number of corrugations in 1.05 m width with small depth of corrugation of 25 mm only. They are also called small section corrugated AC sheets.
3. Tafford tile profile sheets are with 4 corrugation 1.09 m with alternate flat portion the depth of corrugation being 50 mm. Tafford sheets are also referred as Tafford tiles or tile profiled sheets. They are available in different lengths 1.25 to 3 metres in 15 cm increments. They are also called angular section corrugated AC sheets. These sheets are more fragile than the above two corrugated sheets

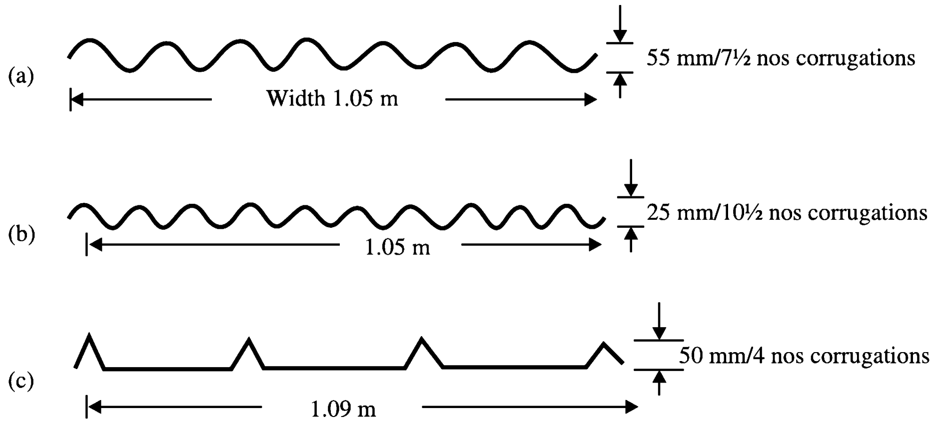


Figure 32.1 AC sheets (a) Big six or deep corrugated sheets, (b) Standard corrugated sheets (c) Semi-corrugated Trafford tiles or tile proffile sheets (All 6 mm in thickness and weight 13 kg/m2 approximately).

Table 32.1 Types of AC Sheets

S. No.	Brand name	Laid width (m)	No. of corrugations	Depth (mm)
1.	Deep corrugated sheets	1.05	$7^1/_2$	55
2.	Standard corrugated sheets	1.05	$10^1/_2$	25
3.	Tafford tiles (Tile profile sheets)	1.09	4	50

(*Note:* 1 and 2 are sold under trade names Everest, Everite, etc.)

AC sheets are commonly used for covering factories, workshops, large halls with long span roof trusses, and so on. These sheets are cheap but have low heat insulation and aesthetic value. In cold climates, condensation takes place in these sheets. The sheets break with the fall of objects (as from coconut trees). They are laid with their smooth side up. Special care should be taken in fixing sheets in cyclonic areas. The choice of the wide spacing ribs (as in big six) is more to fit in scale with *large buildings*. The more closely spaced corrugations are used for *smaller buildings*. The flat trough of the tafford sheets also do not allow unsightly dirt stains as with the corrugated troughs of the other types of sheets. They go well with *buildings of all sizes*.

32.3 CORRUGATED GALVANIZED IRON SHEETS (IS 277–1992)

Corrugated galvanized iron sheets or CGI sheets are used for *roofing and also cladding*. These sheets are manufactured as described in Chapter 18 by coating steel sheets (24 BWG or 0.5 mm thick) with zinc. The coating is specified by the total weight of zinc on both sides. Sheets are classified as class I variety, if the weight of the coating is not less than 750 g of zinc (spelter) per square metre both side inclusive. Sheets are also available with lesser specified nominal coatings of 600 g, 450 g and 375 g per square metre. They are not considered as class I sheets. They are commonly available in lengths of 2.5 m and 3 m having width of 900 mm and 1000 mm. The specified thicknesses of sheets are 0.63, 0.80, 1.00, 1.25 and 1.6 mm. The usual number of corrugations is 10 or 11 per sheet, with the depth of corrugation of 18 mm and a pitch of 75 mm (nominal) as shown in Figure 32.2. These sheets are used in factories and sheds, especially *in colder climates and in places away from marine influence*. In such situations, they wear well and depending on the thickness of coating, they can last for a long time. In many situations, as in assembly halls, G.I. sheets are not very suitable because of the noise level under the roof during rains. The following two tests are usually prescribed to check the quality of these sheets.

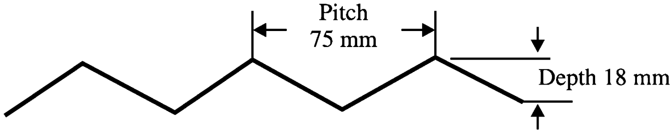


Figure 32.2 Profile of GI sheets.

1. ***Bend test.*** The following bend test is prescribed to test the quality of the zinc coating. It consists of taking a test piece 230 mm long and 75 to 100 mm wide cut both along and across direction of rolling of the sheet at the rate of 2 for every 500 sheets or part thereof. It is wound around a mandrel of diameter as shown in Table 32.2. For passing the test there should be no peeling or flaking of the zinc coating. (Tamil Nadu Building Practice)

Table 32.2 Diameter of Mandrel for Bend Test

Zinc coating (gm/m^2)	Thickness of sheet (mm)				
	1.60	1.25	1.00	0.80	0.63
750	10	10	11	12	14
600	8	8	9	10	11
450	6	6	7	8	8
375	4	4	5	6	6

2. ***Zinc content test.*** A second test that can be specified is to find the content of zinc on both side inclusive by chemical analysis and check whether it is within the specified limits.

32.4 CORRUGATED ALUMINIUM SHEETS

Aluminium is a light weight metal and does not corrode like steel. However, it is more expensive than GI and AC sheets but has a useful life of many years. They require no maintenance and has also a good resale value. The sections available are similar to GI sheets. They are made from aluminium alloy sheets 24 BWG (0.51 mm) thick. Small corrugations of sheets are not considered attractive for large sized buildings. Normal thickness of 0.5 to 0.8 mm has been found to be ample for good performance. We must also remember that even though aluminium sheets can be simply fixed to wooden purlins with aluminium bolts or nails, when aluminium is fixed to steel it should be painted with two coats of zinc chromate or barium chromate based paints or bitumen paint before sheet is laid on them to prevent galvanic action between aluminium and steel.

32.5 PVC ROOFING SHEETS

Extruded rigid PVC corrugated sheets of the unreinforced and reinforced type and transparent sheets with a light transmission of not less than 70 to 80 per cent are available. However, they may not wear well with direct exposure to sunlight. They also are not fireproof. They are used in temporary construction, for car parks, etc. where a very light roofing of pleasing appearance is required. Unreinforced sheets do not last especially when exposed to direct sunlight.

32.6 OTHER LIGHT ROOF MATERIALS

A large number of other light roofing sheets made of other materials are also available. Some of them are as follows:

1. ***Glass fiber reinforced plastic sheets.*** Corrugated plastic translucent sheets made from thermosetting polyester resins and glass fibre reinforced with different profiles and light transmission are available as light roofing materials. These sheets unlike GI and aluminium sheets have little resale value.
2. ***Bituminous sheets.*** Light roofing made of bitumen and paper pulp is available for covering of temporary sheds. They are cheap but their life is very short (3 to 5 years only) and the materials once perished have no resale value.
3. ***Red mud corrugated roofing sheets.*** Red mud is material is of recent origin and is made from waste materials derived in aluminium industry. It is combined with polymers to form a number of industrial products like corrugated roofing sheets, door panels, wall tiles, etc. The roofing sheets are cheap and more durable than bituminous sheets. Nowadays, they are extensively used as a light roofing material. It is also very flexible so that special sections need not be used for ridges and valleys. The sheet itself can be bent to the required shape and then used. They are perhaps the cheapest, moderately durable roofing sheets which are now available in India. They are very popular for temporary construction.

SUMMARY

There are a large number of light alternative roofing materials available in the market. The choice of the material depends on the use of the building, the available finances and aesthetics.

REVIEW QUESTIONS

1. (a) How do we classify roofs of buildings?
(b) Give a list of the commonly used materials for covering pitched roofs?
(c) Describe the type of AC sheets available in India?

2. (a) What are GI sheets?
(b) Under what situations would you use GI sheets?
(c) What are the tests prescribed to find the quality of GI sheets?

3. Write short notes on:
(a) Aluminium sheet for roof covering
(b) Reinforced plastic roofing sheets
(c) Everest and Tafford sheets
(d) Red-mud corrugated sheets.

REFERENCES

[1] IS 459–1992: *Corrugated and Semicorrugated Asbestos Cement Sheets—Specifications.*

[2] IS 277–2003: *Galvanised Steel Sheets (Plain and Corrugated)—Specification.*

CHAPTER 33

Pipes Used in Building Construction

33.1 INTRODUCTION

In building construction, there are mainly four types of piping system to be designed. They are

1. The water supply piping system
2. The rainwater disposal system above the ground
3. The soil and waste disposal system above the ground (This system disposes water from water closets and washbasins, etc.)
4. The below-ground drainage system carrying soil and waste water to septic tanks or town sewers

We will study the design and construction of these piping systems in building construction. In this chapter, we will deal only with the various types of pipes that are available for the above purposes. The principal types of pipes used are the following:

1. Cast iron pipes and fittings
2. PVC pipes
3. GI pipes
4. Stoneware pipes
5. AC pipes

Even though all these types of pipes are available, PVC pipes are, nowadays, used extensively for all the purposes. However, we should be aware of the fact that ordinary PVC pipes are not very durable when exposed to direct sunlight outside the buildings. Moreover, they are costly. The choice of the pipes will depend on the expected durability and also the cost. For low cost construction, low cost materials have to be selected.

33.2 CAST IRON PIPES

Cast iron pipes and fittings are in use for soil, waste and rainwater pipe system for the past hundred years. These pipes are made by the *sand cast process* or by *spinning*. *Sand cast pipes* are made by pouring molten grey cast iron into vertically mounted sand moulds. They are available in 1.5, 1.8 and 2.0 metre length and 5 and 6 mm thickness. *Spun pipes* are made by pouring molten grey cast iron into a revolving water cooled mould, producing a seamless pipe in length upto 3 metres with thickness less than sand cast pipes. As described in Section 18.10.2, *ductile cast iron pipes* are also, nowadays, available in the market. They are as good as steel pipes in strength and are as durable as cast iron. However, these pipes are costly and are usually specified for public buildings.

33.3 PLASTIC PIPES

There are many types of plastic pipes popularly available for building construction. These pipes are costlier than AC pipes but cheaper than GI pipes. The available types of plastic pipes are the following: (See Section 24.7.1)

1. Unplasticized PVC (UPVC) or rigid PVC pipes for use with cold water
2. Plasticized PVC pipes which are plasticized with addition of rubber. This makes it less brittle but with lower strength and lower working temperature than UPVC pipes
3. Chlorinated PVC (CPVC) pipes which can withstand higher temperatures up to 120°C (It can be used to carry hot water also)

Different types of PVC pipes are used for electrical conduits, water supply (cold and hot), roof drainage, waste and ventilating systems.

In addition to PVC, polyethylene (PE) and polybutane (PB) pipes are also available but they are less commonly used.

Ordinary PVC pipes are used as electric conduits for concealed wiring. The basic raw material for all these pipes is the UPVC. Other ingredients like stabilizers, fillers, pigments, lubricants are added for special purposes. The stabilizer protects the system from deterioration due to photochemical reaction of ultraviolet radiation when exposed to sunlight. They are made by extrusion under high pressure. IS 13592, IS 4984 and IS 4985 give the specifications for the following:

(a) Pipes for soil discharge system inside building including ventilation and rainwater system
(b) Pipes for portable water supply
(c) Pipes for sewerage and industrial effluents

For pipes used in soil and waste discharge systems, the thickness of the wall will be larger than that of used for roof drainage. These pipes now are available with or without socket ends and also with threaded ends like GI pipes. Rigid PVC pipes are used for distribution of water with temperatures below 45°C. At higher temperatures, the strength of the pipes decreases. Similarly, ultraviolet radiation from sunlight as well as frequent changes in temperature, reduces the life of PVC pipes considerably. As far as possible, they should not be exposed to direct sunlight. If they are shaded or concealed, then they last very much longer. They should be concealed in masonry only after proper tests for leakage are completed. The advantages and disadvantages of PVC pipes have been dealt with in Section 24.7.1.

33.4 GALVANIZED STEEL (GI) PIPES

GI pipes are made from steel pipes. The galvanizing process deposits a thin coating of zinc which protects it from corrosion. They are available in light, medium and heavy grades depending on the thickness of the metal. For a 15 mm GI pipe, the thicknesses are 2.0, 2.65 and 3.25 mm for the light, medium and heavy grades, respectively. Generally, the medium grade pipes are used for internal plumbing in buildings. GI pipes were once the most popular material used in water supply inside buildings. However, these pipes corrode easily if it carries brackish water or concealed in lime concrete and brickwork or buried under the ground. GI pipes of up to 150 mm nominal diameter are available in the market. They are costlier than PVC pipes.

33.5 STONEWARE PIPES

The manufacture of stoneware pipes has been discused in Section 27.13. Pipes of internal diameters 100 mm to 600 mm are available with thickness varying from 12 mm to 43 mm. A good stoneware pipe should give a sharp clear tone when struck with a light hammer. These pipes are cheap and are extensively used as underground drainage pipes in low cost construction. Usually, these pipes are laid on an even bed of concrete and further treated as specified for laying in different types of soils. However, laying of these pipes requires experienced workmen and good supervisior. Hence, PVC pipes are being preferred to these pipes in many places.

33.6 ASBESTOS CEMENT (AC) PIPES

Asbestos cement pipes were once very popular for drainage. They are cheaper than PVC pipes. They are still used for drainage of rainwater from roofs, soil, waste and also for ventilation. They come in two profiles—one with beading around the socket (WB) and the other without beading around the socket (WOB). The latter type is more common than the former. The pipes come in lengths of 3 m. The principal defects of these pipes are that they are heavy and they break easily. The unbroken part cannot be reused easily as in the case of PVC pipes. However, nowadays, AC pipes are being replaced by PVC pipes in higher class buildings for many reasons such as brittleness of AC pipes, availability of PVC pipes in long lengths, easiness in fixing PVC pipes to walls and lack of trained people to fix traditional types of pipes.

33.7 CONCRETE PIPES

Unreinforced pipes of small diameters as well as reinforced and prestressed concrete pipes of large diameters are available for water supply and other uses. Small unreinforced concrete pipes are very much used for drainage of rainwater and for irrigation works and can be made as a cottage industry. Large diameter pipes are generally made by spinning and are used for major watersupply works.

SUMMARY

Pipes are used for different purposes in building construction. In general, PVC pipes have taken over all other types of pipes for common use. In general, the following recommendations can be made for use of pipes in building construction:

1. Pipes for electrical conduits. PVC pipes.
2. Building service connection placed underground. Use PVC pipes as GI pipes get rusted with time.
3. Internal water supply. GI pipes (if water is not brackish) or Rigid PVC (for cold water). GI pipes or plasticized (special) PVC pipes for hot water.
4. Rainwater drainage. AC pipes, PVC pipes or CI rainwater pipes (Nowadays, PVC pipes are preferred.)
5. Sewer construction. Stoneware pipes (Cast Iron pipes, unplasticized rigid PVC pipes, AC pipes or cement concrete pipes)
6. Ventilating pipes, (trap and vent pipes). AC pipes, PVC pipes, CI pipes. Nowadays, PVC pipes are more popular than AC pipes.

In all cases, the final decision will be the cost of piping, availability of good workman to lay the pipes and cost of construction. Construction cost in laying PVC pipes will be the minimum even though their material cost will be high for this work.

REVIEW QUESTIONS

1. For what items of work are pipes used in building construction? Give the usual types of pipes that can be used for each of them.

2. Explain what is meant by each of the following and indicate what types of pipes can be used for them:
   (a) Rainwater drainage
   (b) Sewerage disposal
   (c) Internal water supply
   (d) Ventilation.

REFERENCES

[1] SP 57–1993: *Handbook on Pipes and Fittings for Drinking Water Supply.*

[2] IS 1537–1976: *Specification for Vertically Cast Iron Pressure Pipes for Water, Gas and Sewage. (IS 1538–1992 for Cast Iron Fittings).*

[3] IS 1536–2001: *Centrifugally Cast (Spun) Iron Pressure Pipes for Water, Gas and Sewage (SP).*

[4] IS 13592–1992: *Unplasticized PVC (UPVC) Pipes for Soil and Waste-discharge Systems Inside Building Including Ventilation and Rainwater Systems—Specificaion.*

[5] IS 4984–1995: *Specification for High Density Polyethelene Pipes for Potable Water Supply.*

[6] IS 4985–2000: *UPVC Pipes for Portable Water Supplies Specification.*

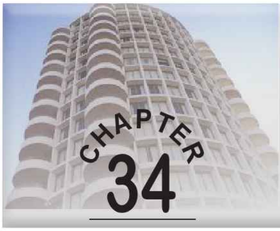
[7] IS 3076–1985: *Low Density Polyethelene Pipes for Potable Water Supplies (SP).*

[8] IS 7634 *Parts 1 to 3: Code of Practice for Plastic Pipe for Potable Water Supplies (Part 1: Choice of Materials and General Recommendation, Part 2: Laying and Joining Polyethylene (PE) Pipes, Part 3: Laying and Joining UPVC Pipes.*

[9] IS 1239–*(Part 1) 1990 and (Part 2) 1992: Specifications for Mild Steel Tubes, Tubulars and Other Wrought Steel Fittings.*

[10] IS 651–1992: *Salt-glazed Stoneware Pipes and Fittings—Specifications.*

[11] IS 1626–1994: *Asbestos Cement Building Pipes and Pipe Fittings, Gutters and Gutter Fittings and Roof Fittings—Specifications* (*Part 1, Pipes and Pipe Fittings; Part 2, Gutters and Gutter Fittings; Part 3; Roofing-fittings*).



Door and Window Fittings

34.1 INTRODUCTION

The following fixtures, fastening and devices are the standard items specified for doors and windows:

(a) Door and window hinges
(b) Door and window bolts
(c) Door handles
(d) Door locks
(e) Other wood fastenings
(f) Fixing devices

When we specify doors, we also specify a schedule of fittings as shown in Table 34.1.

Table 34.1 Schedule of Fittings for Doors and Windows

No.	Item	Butt hinges	Sliding bolt	Tower bolt	Handle
1.	Panelled or glazed double leaf door shutters	6100 mm	1300 mm	3250 mm	3100 mm
2.	Panelled or glazed single leaf door shutter	3100 mm	1250 mm	2250 mm	2100 mm
3.	Double leaf window shutter, panelled or glazed	675 mm	–	3150 mm	–

We will examine some of these filtings that are commonly used.

34.2 DOOR AND WINDOW HINGES

Some of the commonly available hinges are shown in Figure 34.1. They are available in steel (plain and oxidized) brass and aluminium. It is advisable to use steel for heavy doors as aluminium as well as the plastic washers provided in them tend to wear away soon under heavy loads.

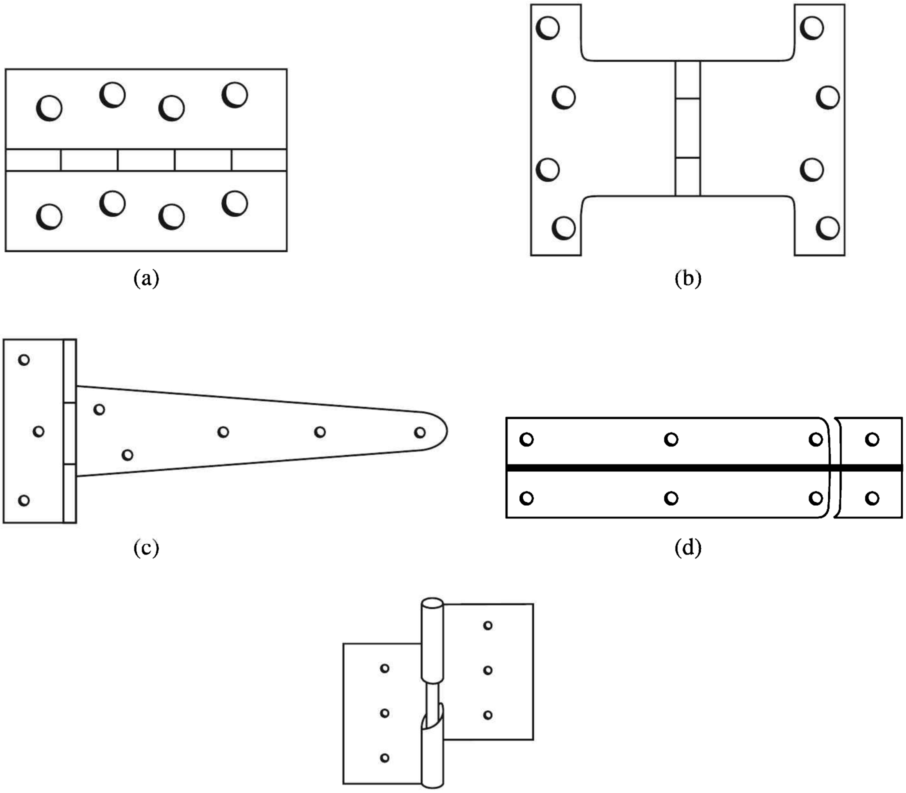


Figure 34.1 Hinges (a) Butt hinges (b) Parliament hinges (c) Garnet hinge (d) Piano hinges (e) Rising butt hinges.

The following are the common door and window hinges:

1. ***Butt hinges.*** They are commonly used for doors and windows as shown in Table 34.1.
2. ***Pin hinges.*** They are similar to butt hinges except that the central pin can be removed so that the two can be separately fixed one to the frame and the other to the shutter.
3. ***Parliament hinges.*** They allow the doors and windows to be kept open, with the shutter resting parallel to the wall. They are very useful in planning doors for passages.
4. ***Garnet hinges.*** They are usually used for ledged and battened doors. The short arm is screwed to the door frame. They are also known as T hinge.
5. ***Counter flap hinges.*** They are used in folding doors. It has three parts with two pin centres so that the two leaves can be folded back to back.
6. ***Strap hinges.*** They are used generally for heavy doors for gates, garages and also ledged and laced doors as with Garnet (T) hinge.
7. ***Piano hinges.*** They are generally used for shutters of cupboards, wardrobes, etc.
8. ***Spring hinges.*** They are used for automatically closing shutters. Single acting and double acting types are available in mild steel, (plain and oxidized) aluminium and brass.

9. ***Rising butt hinges.*** They are used for automatically closing doors. The shutter when opened rises up and when left closes itself by gravity.

34.3 BOLTS

Another common fixture to doors and windows is the bolt. The most common types of bolts are shown in Figure 34.2. They are available in aluminium, brass or mild steel.

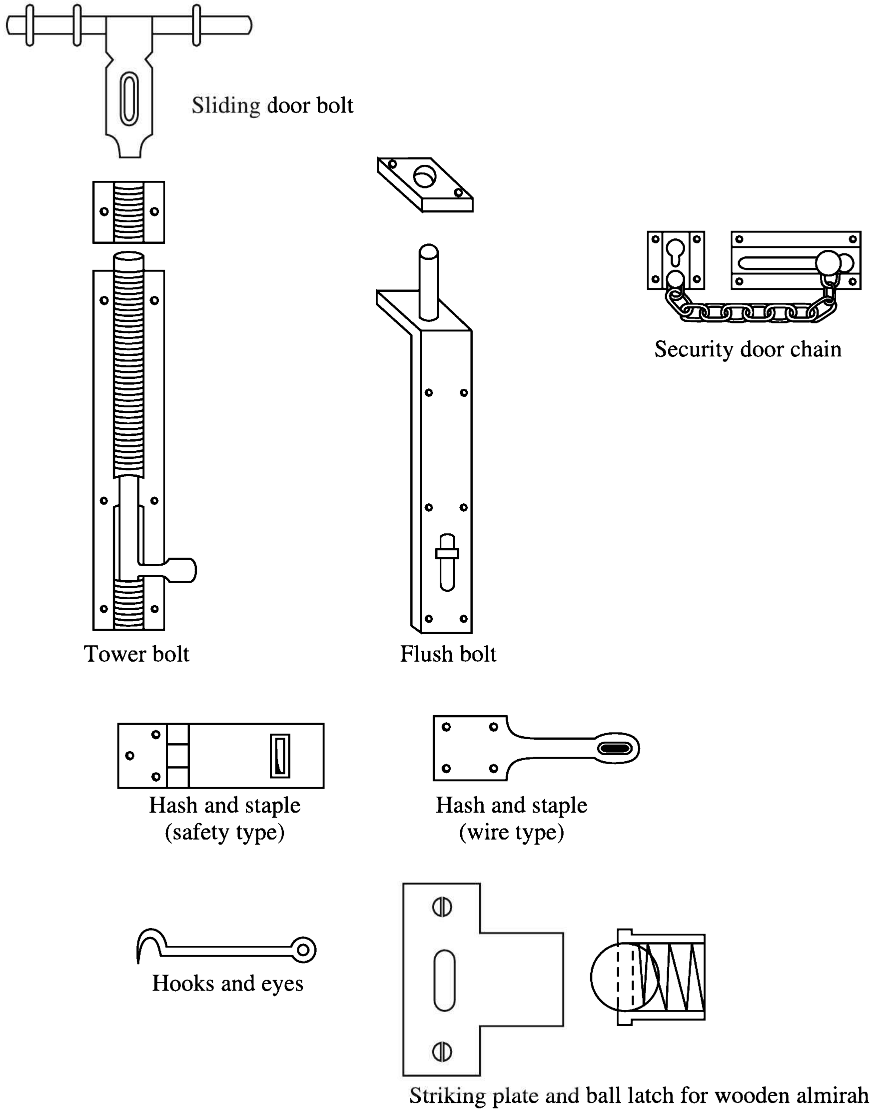


Figure 34.2 Same common door and carpentary fittings.

1. ***Tower bolts.*** They are very commonly used on doors and windows and are available in aluminium, steel and brass.
2. ***Sliding door bolts (Aldrops)*** (IS 281 and 2681). They are used for doors where pad-locks are used. (Figure 34.2)
3. ***Flush bolt*** (IS 5187). They are used for cupboards and sliding windows for bolting the shutter flush with the exterior surface. (Figure 34.2)

34.4 HASP AND STAPLE

They can be of two types as shown in Figure 34.2. The safety type are made of mild steel, cast brass or aluminium. The part with the hinged extension is the hasp and the fixed part with hook is the staple. The wire type is usually made of steel.

34.5 HANDLES

Handles are usually fitted to doors. There are various types of handles made of mild steel, aluminium alloys and brass.

34.6 LOCKS

There are many types of locks available in the market for fitting to doors. The commonly used ones are the following. They are shown in Figure 34.3.

1. **Mortice lock.** It is called by this name as the locking part is placed in a mortice (as in mortice and tennon wood joint). There are two types. In the first, the spindle or handle is placed above the key hole. This is called the *vertical type*. The other type is the *horizontal type* where the handle is placed horizontally away from the key hole. Which one is to use, depends on the width of the lock rail and cost. There are two bolts (latch bolt and lock bolt, for these locks. The latch bolt keeps it closed and lock bolt locks the door.
2. **Mortice dead lock.** This type has only a lock bolt operated by a key. Some other device is needed to keep it closed when it is unlocked.
3. **Rim locks.** Where the door style is too thin to accommodate a mortice lock we use a rim lock. The lock is fixed to the face of the doors.
4. **Night latches.** It acts as a latch from inside and lock from outside for use on front doors. Latches of rim and mortice type are available. The rim type is fixed to the inside face of door. (Spring lock of an outer door which locks when the door is closed is called a *latch.*)
5. **Pad locks.** There are many types of pad locks that can be used to lock doors fitted with sliding door bolts.
6. **Cupboard and wardrobe locks.** They are usually made of brass. There are heavy and light duty locks. They are fitted to the side of the moveable shutter.

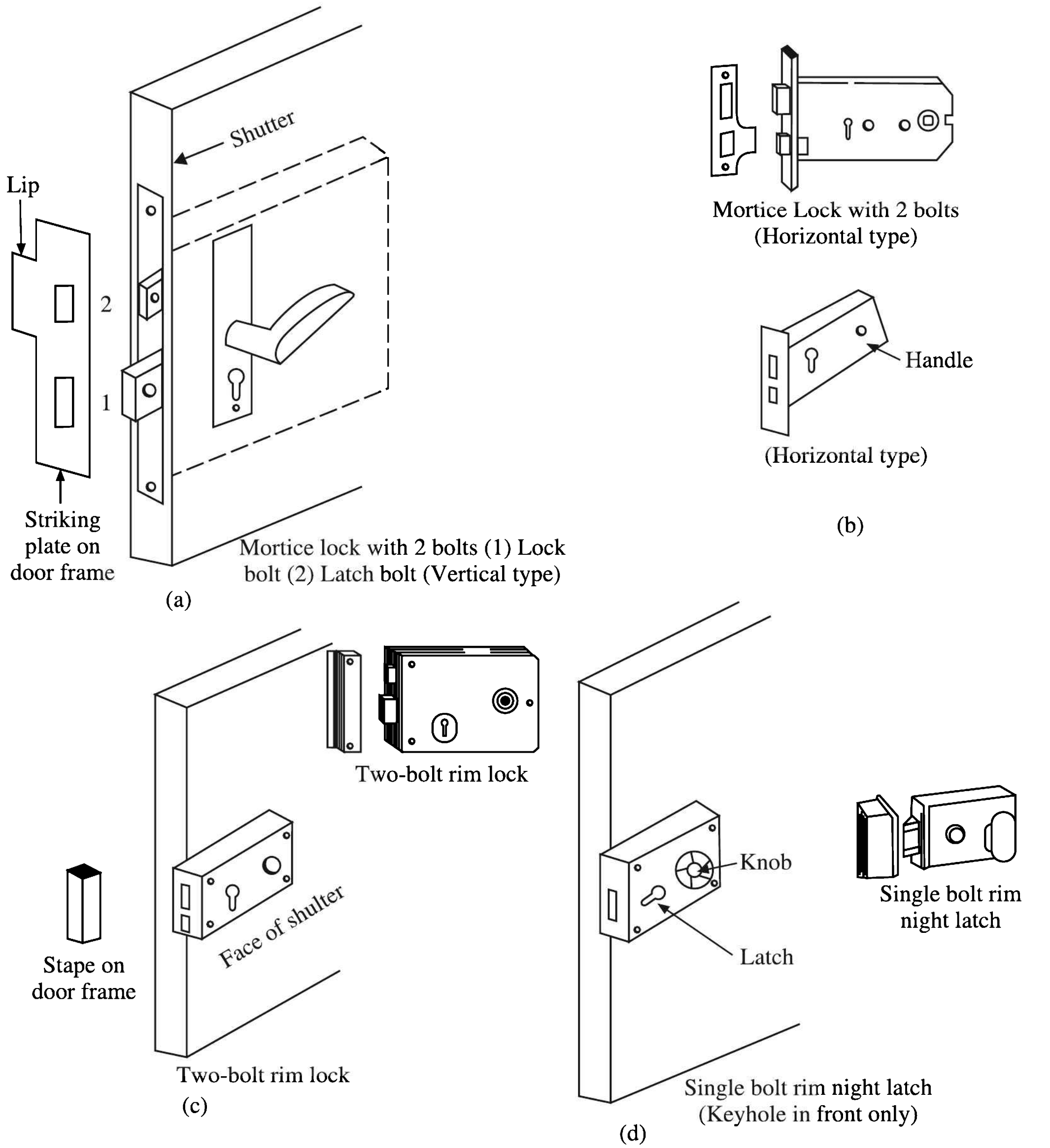


Figure 34.3 Usual types of door locks used in buildings—Mortice locks and rim locks. (a) Mortice lock vertical type (b) Mortice lock horizontal type (c) Two-bolt rim lock (d) Single bolt rim night latch.

34.7 OTHER FASTENINGS TO DOORS AND WINDOWS

There are many other types of fittings for doors and windows. Some of them are listed below:

1. ***Hooks and eyes.*** The are commonly used for windows for keeping them open.

2. ***Window stays.*** They are the devices to keep the windows, fanlights, etc. open in the desired place. They are adjustable to keep the shutters in different positions.
3. ***Chain with hook.*** They are used for ventilators.
4. ***Door stoppers of different types.*** Magnetic types stoppers are used to keep the doors fully open.
5. ***Hydraulic door closers.*** They are fitted on the top of doors and consist of a hydraulically operated cylinder. Universal type is suitable for both right hand and left hand opening doors. These are two types namely the bottle type and tubular type. The closing time can be adjusted between 5 to 20 seconds by an adjustable screw.
6. ***Ball catches for wooden almirah.*** They consist of a strike plate and a catch with a ball and spring. They are generally used for cupboards. When closed, the door is retained in position by the ball pressing against the plate by the action of the spring.
7. ***Magnetic catches for wooden cupboards.*** They can be used instead of ball catches. There is a small magnet on one side which is attracted to a small steel plate, thus closing the door by magnetic action. They can also be used for doors for children which we do not want to bolt.

34.8 FIXING DEVICES

The fittings described above should be fixed to the wood with suitable fasteners. Some of them are as follows:

1. ***Nails.*** They are more often used for permanent connections like connecting two wooden pieces. They come in different sizes and shapes for specific uses. The following types of nails are commonly used:
   (a) Round wire nails
   (b) Oval wire nails
   (c) Floor brads (tapered nail to connect floor boards)
   (d) Lath nail (square small nails used to connect thin wooden boards)

As an example, reepers for tiles are usually nailed on to rafters by wire nails.

2. ***Screws.*** Screws of different sizes and forms are used to fix items in doors and windows. They are also used instead of nails for fastening wood to wood. In many cases, fixing by screws is preferred because of the following reasons:
   (a) They can be fixed without hammering.
   (b) They can be removed easily if needed.
   (c) They do not result in splitting of timber (which are of brittle quality) and
   (d) Screw joints are stronger than nail joints because of their better holding power.

In Generally, screws are available as round headed screws and counter headed screws. While using the latter, the head comes flush with the material joined.

3. ***Coach screws.*** Coach screws are large sized screws for fabrication of wooden structures.

4. ***Bolts.*** Bolt consists of an assembly of nut and washer. They are used for large sized wooden structures and very often for fabrication of steel structures.

34.9 RCC FRAMES FOR DOORS AND WINDOWS

For economy in construction, RCC frames with wooden shutters are offer specified for many low cost housings. The difficulty has been for evolving a proper way to fix the shutters to the frame. Standard methods for such fixing have been evolved which we will study in Building construction.

SUMMARY

There are a large number of carpentary fittings available for fixing to doors, windows, cupboards and so on. We should use as small a number as necessary in our works as they are expensive and may also become unusable unless they are frequently operated. Only fittings with IS markings should be used in construction.

REVIEW QUESTIONS

1. Write short notes on the following:
   (a) Various types of hinges used for doors and windows
   (b) Various types of bolts used for doors and windows

2. Give a brief description of the types of locks that are available for fitting on doors and cupboards.

3. Write short notes on:
   (a) Mortice locks and rim locks
   (b) Parliamentary hinges
   (c) Piano hinges
   (d) Hasp and staple
   (e) Night latch

REFERENCES

[1] IS 1341–1992: *Steel Butt Hinges—Specification.*

[2] IS 362–1991: *Parliament Hinges—Specification.*

[3] IS 363–1993: *Hasps and Staples—Specification.*

[4] IS 364–1993: *Fanlight Catch—Specification.*

[5] IS 204–1991: *Tower Bolt—Specification (Part 1, Ferrous Metals; Part 2, Nonferraus Metls).*

[6] IS 205–1992: *Nonferrous Metal Butt Hinges—Specification.*

[7] IS 206–1992: *Tee and Strap Hinges—Specification.*

[8] IS 208–1996: *Door Handles—Specification.*

[9] IS 3818–1992: *Continuous (Piano) Hinges—Specification.*

[10] IS 452–1973: *Door Springs, Rat-tail Type—Specification.*

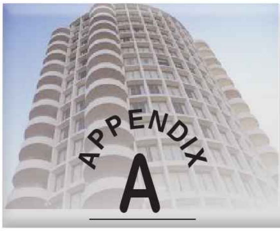
[11] IS 453–1993: *Double-acting Spring Hinges—Specification.*

[12] IS 281–1991: *Mild Steel Sliding Door Bolts for use with Pad Locks—Specification.*

[13] IS 2681–1993: *Nonferrous Metal Sliding Door Bolts (Aldrops) for Use with Padlocks. Specification.*

[14] IS 3847–1992: *Mortice Night Latches—Specification.*

[15] IS 9131–1979: *Specification for Rim Locks.*



Syllabus for Laboratory Work

A.1 GENERAL

This textbook is based on Part I of the syllabus on construction materials (or building materials) prescribed for the civil engineering students of Anna University, Tamil Nadu for the second semester of their eight semester course. The total number of lecture periods allotted is 45.

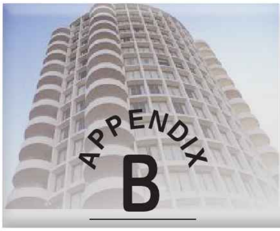
Part II of the course in construction materials is the Construction Materials Laboratory.

A.2 SYLLABUS FOR CONSTRUCTION MATERIALS LABORATORY

The following is the syllabus for construction materials laboratory of three hours duration for each class. (For details of tests see corresponding IS given in the text.)

Construction Materials Laboratory

1. **Tests on Stones**
   Texture, Density, Compressive Strength
2. **Tests on Bricks**
   Compressive Strength, Water Absorption, Efflorescence
3. **Tests on Cement**
   Specific gravity, Soundness, Consistency and Setting times, Vicat, Le Chatelier's and Blain's apparatus
4. **Tests on Coarse and Fine Aggregates**
   Crushing strength, Impact resistance, Grading, Organic impurities, Elongation index, Specific gravity, Fineness modulus, Bulking of sand.
5. **Tests on Concrete**
   Slump cone, Compaction factor, Flow table, Cube and cylinder strength, Modulus of rupture, Vee bee apparatus
6. **Additional Tests**
   Test on steel rods for reinforced concrete: tensile test, modulus of elasticity and percentage of elongation, yield point, bend test.



Model Question Paper on Building Materials

B.1 INTRODUCTION

There is a need in our Indian universities for the examination question paper setters to set questions to test the students' understanding of the subject rather than to test the students' memory of the data presented in their textbooks. A model question paper on Building Materials for first or second year civil engineering degree students is attempted in this Appendix.

B.2 OBJECTIVE OF QUESTIONPAPER

In this book, the subject of building construction has been presented in 34 sections. The subject is presented as lecture-based chapters, so that it would be easy for the lecturer to prepare himself for the lecture and also for the students to review the subject. Another reason for this presentation is to make it easy for an examiner to set the question paper so that the questions can be easily spread over the whole subject.

As the main object of teaching a very practice-oriented subject like Building Materials is to make the students familiar with the current practice, it will be good if while setting examination question papers, we divide the subject into the following two groups.

Group I: Traditional materials we meet with in everyday practice such as stone, bricks, cement, concrete, steel, wood, flooring materials, roofing materials, paints, pipes, etc. and about which we should have a good knowledge.

Group II: New materials, such as concrete chemicals materials for joints, ceramics, ductile iron, etc. which are new, but with which the students should be also familiar.

We should ensure that the students have a good knowledge of the traditional materials in Group I and also know about the development of the new materials in Group II. We are also interested more in the use of these materials in the field rather than their chemistry, manufacture, etc. unless it is reflected in their performance in the field.

B.3 FORMAT OF QUESTION PAPER

With the above objectives, the following question paper in presented as a model for university examinations. The format adopted is the same as that adopted by many universities in India like Anna University in Tamil Nadu. The format is as follows for a 3-hour examination for 100 marks.

Part A: 10 or more short answer questions of 2 marks each
(to take 2 minutes each)

Part B: (a) 1 compulsory descriptive question on an important topic for 16 marks
(b) 4 or more descriptive questions with an alternative question as choice each for 16 marks
(Each question to take 30 minutes)

B.4 MODEL QUESTION PAPER ON CONSTRUCTION MATERIALS

Answer all questions

Part A (10 × 2 marks = 20 marks)

1. What is meant by stock bricks?
2. How do you make mud mortar?
3. Why are bricks wetted and concrete hollow blocks, not wetted in masonry construction?
4. How do you make fatlime into by hydraulic lime?
5. What are the grades of cement available in the Indian market?
6. State how TMT bars are made.
7. What is the minimum grade of concrete to be used in reinforced concrete construction?
8. What is anodizing of aluminium?
9. What paint will you recommend for (a) iron grillwork (b) exterior of a multistorey building?
10. What is the difference between (a) rim locks and (b) mortice locks?

Part B [5 × 16 marks = 80 marks]

11. (a) Explain the difference between the development of strengths of lime mortar and cement mortar.
(b) State why do you add sand to make lime mortar and cement mortar.
(c) Describe the procedure for making cement mortar by handmixing.
12. Briefly describe any five tests prescribed to test the quality of bricks for masonry construction.

or

Describe briefly three common types of roofing sheets used in construction of buildings.

13. (a) Explain Abram's law.
(b) How do you test the quality of groundwater for durability of concrete and suitability of maxing water for making concrete for R.C. construction?

or

(a) Enumerate the common defects in timber.
(b) What are (i) plywood, (ii) particle board and (iii) blockboard. Give rough sketches to illustrate your answers.

14. (a) What is the difference between ceramic wall tiles and ceramic floor tiles?
(b) Briefly describe three types of ceramic floor tiles available in the Indian market.

or

(a) What are asphalt, bitumen and tar?
(b) What is meant by bitumen 90/100 penetraction?
(c) Explain two uses of these materials in building construction.

15. (a) Briefly describe the different types of PVC pipes used for building construction.
(b) Enumerate five advantages of PVC pipes over GI pipes.

or

Describe with sketches the manufacture of (a) sheet glass (b) plate glass (c) float glass. How do they differ from each other in their quality? Where will you use each type in construction of buildings?

Index

Building Materials

P.C. Varghese Second Edition

This practice-oriented book, now in its second edition, presents a lucid yet comprehensive coverage of the engineering properties and uses of the materials commonly used in building construction in India. Profusely illustrated with tables and diagrams, the book brings into light the basics of building materials and their specifications. Besides giving information regarding the traditional building materials, the text now acquaints the reader with up-to-date and in-depth information pertaining to modern materials available in the market. The references to IS codes and standards make this text suitable for further study and field use.

The second edition possesses some substantial changes in Chapters 12, 13, 14 and 20. Now, the book offers a new section on durability of concrete in Chapter 12; a modified section regarding revision of IS 10262 (1982) code on concrete mix design to IS 10262 (2009) and a new section on classification of exposure conditions in Chapter 13; and a new section relating to large advances made in concrete construction and repair chemicals in Chapter 14. Besides, the contents of Chapter 20 have been completely updated, with a particular emphasis on the extensive use of aluminium in building construction.

Primarily intended for the students pursuing undergraduate degree (B.E./B.Tech.) and diploma courses in civil engineering and architecture, the book, on account of lecture-based presentation of the subject, should also prove eminently utilitarian for the young teachers to use it in their classroom lectures as well as for practising engineers to get a clear understanding of the fundamentals of the subject.

NEW TO THE SECOND EDITION

- Review questions at the end of each chapter enable the reader to recapitulate the topics.
- Considerable attention is given on field practice.
- Syllabus of laboratory work on construction materials and a model question paper (Anna University) are given in appendices to guide the reader.

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