6. Research and Development In addition to the above mentioned works, a civil engineer has to engage himself in research and development to achieve economy and to improve the efficiency to meet the present and future needs.

3.3 CONSTRUCTION MATERIALS—BRICKS

3.3.1 Introduction

As an engineer, one must know about the materials used in the construction site. All structures are constructed of materials known as engineering materials or building materials. It is necessary for an engineer to be conversant with the properties of such materials.

The service conditions of buildings demand a wide range of materials with specific properties. Hence the properties of the materials are to be studied properly to select suitable building materials. In this section and in the subsequent sections, the properties and uses of some building materials, such as bricks, stones, cement, concrete and steel are discussed.

The common brick is one of the oldest building materials and it is extensively used at present because of its durability, strength, reliability, low cost, etc. Bricks are obtained by moulding clay in rectangular blocks of uniform size, then by drying and burning these blocks in brick kilns.

3.3.2 Qualities of Good Bricks **[Nov, Dec 2010, 2011, 2014; May, June 2013; Apr, May 2015, Regulation 2008]**

1. Bricks should have perfect edges, well-burnt in kilns, copper coloured, free from cracks with proper rectangular shape and of standard size (19 × 9 × 9 cm).
2. Bricks should give a clear ringing sound when struck with each other.
3. Bricks must be homogeneous and free from voids.
4. The percentage absorption of water by weight should not be greater than 20 per cent for first-class bricks and 22 per cent for second-class bricks when soaked in cold water for 24 hours.
5. Bricks should be sufficiently hard, i.e., no nail impression must be present when scratched. The average weight of bricks should be 3–3.5 kg.
6. Bricks should not break when dropped from a height of 1 m.
7. Bricks should have low thermal conductivity and should be soundproof.
8. Bricks should not show deposits of salts when immersed in water and dried.
9. The minimum crushing strength of bricks must be 3.5 N/mm^2.

3.3.3 Classification of Bricks **[May, June 2009, 2010, 2014; Nov, Dec 2010, 2014; Apr, May 2015, Regulation 2008]**

Bricks are classified based on the manufacturing process adopted. The classification is given as follows:

1. First-class bricks are table-moulded and of standard shape. These comply with all good qualities of bricks and are used for superior and permanent works.
2. Second-class bricks are ground-moulded and burnt in kilns. The surfaces of such bricks are rough and are slightly irregular in shape. Such bricks are used with a coat of plaster.
3. Third-class bricks are ground-moulded and are burnt in clamps. These bricks are not hard but rough with irregular and distorted edges. These give a dull sound when struck with each other. They are used for unimportant and temporary structures and at places where there is less rainfall.
4. Overburnt bricks with irregular shape and dark colour are classified as the fourth class bricks. These are used as aggregates for concrete in foundations, floors, roads, etc.

3.3.4 Uses of Bricks **[Nov, Dec 2010; May, June 2013; Apr, May 2015, Regulation 2008]**

1. Bricks are mainly used for the construction of walls.
2. Bricks when moulded in the shape of a gutter can be used as drains.
3. Bricks with cavities known as hollow bricks can be used for insulation purposes and because of their light weight they are more useful in speedy constructions.
4. Paving bricks prepared from clay containing higher percentage of iron can be used for pavements, since they resist abrasion in a better way.
5. Bricks with holes are used in multi-storeyed framed structures.
6. Fire bricks made of fire clay can be used as a refractory material.
7. Sand-lime bricks are used for ornamental work.
8. Bricks are used in the construction of compound walls, columns, etc. Broken pieces of bricks are used as aggregates in concrete.
9. Bricks of superior quality can be used in the facing of a wall.
10. Bricks are used in the construction of chimneys and other special works.

3.3.5 Constituents of a Brick **[Nov, Dec 2011, 2014]**

1. Alumina It is the chief constituent of clay. A good brick should have 20–30 per cent of alumina. This imparts plasticity to the earth.

2. Silica It exists in clay in a free or combined form. A good brick earth should contain about 50–60 per cent of silica. The presence of silica prevents cracking, shrinking and warping of raw bricks. It imparts uniform shape to bricks. The durability depends on proper proportion of silica.

3. Lime Up to 5 per cent of lime is desirable in good brick earth. It prevents shrinkage in raw bricks. Sand alone is infusible, but it fuses at kiln temperature due to the presence of lime. Bricks may melt and lose their shape due to excess of lime content.

4. Oxide of iron This gives the red colour to bricks. A small quantity of iron oxide up to 5 or 6 per cent is desirable.

5. Magnesia This imparts yellow tints to bricks and it reduces shrinkage.

Advantages of using bricks

The following are the advantages of bricks over other construction materials, like stone, concrete etc.,

(a) Bricks are cheaper and easy to handle.
(b) They are of standard size and hence easy to have proper bonding.
(c) Consumes less mortar when compared to stone masonry.
(d) Labour required for brick masonry is less.
(e) Brick walls can be raised to a larger height, when compared to stone masonry.
(f) Because of regular size the surface of wall will be plane and given a neat appearance.
(g) Brick masonry consumes, less mortar for plastering.
(h) Easy to drill holes for fixing service connection line.
(i) Bricks have low thermal conductivity and high sound insulation properties.
(j) They possess very high resistance to fire.
(k) They are non–combustible and non–inflammable.

Disadvantages of using bricks

(a) The compressive strength of brick is less compared to stone and concrete.
(b) Water absorption is more than that of stone or concrete.
(c) Only a selected variety of clay can be used for manufacture of bricks
(d) Kilns are required to be constructed for manufacturing bricks.
(e) It has got a very low tensile strength compared to other building materials.

3.3.6 Tests on Bricks

The following are the field tests by judgment for assessing the quality of bricks.

Field tests

1. The bricks should be truly rectangular in shape with sharp edges and plane faces and of the same size.
2. They should be hard and well burnt and should give a metallic ringing sound when struck with a steel rod.
3. They should be of uniform red colour and of fine texture.
4. When the bricks are dropped on the ground from one metre height, they should not crack or break.
5. They should be free from cracks, fissures, pebbles or nodules of free lime.

Lab Tests

1. Test for water absorptions

(a) 3 samples of clean well dried bricks are taken and their dry weight is found out individually.

(b) The bricks are then immersed in water for 24 hours.

(c) After 24 hours, the bricks are taken out, surface dried and weighed in a balance and wet weight found out.

(d) If the wet weight of each bricks is W_2, the percentage water absorption of each brick

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

(e) The average percentage of water absorption of three samples is the water absorption of the bricks.

Required standard The average absorption should not be greater than 20%. Too much of water absorption indicates under burnt condition and poor strength.

2. Test for efflorescence (For the presence of salt)

Salts like sulphates of calcium, magnesium, sodium and potassium present in the brick will cause efflorescence on the brick surface, when they get dissolved in water. Bricks containing too much of salt are less resistant to weathering and will have poor strength.

1. Three samples of bricks are immersed in good water for 24 hours.
2. After 24 hours, the bricks are taken out and examined for white patches of salt on the surfaces.
3. If the white patches of salt present are heavy, the bricks are poor and are to be rejected.
4. If the while patches present are small to medium, the bricks can be accepted.

3. Test for compressive strength

The load carrying capacity of bricks is increased, as the compressive strength increases.

(a) Three samples of bricks are taken and immersed in good water for 24 hours.

(b) After 24 hours of immersion, the bricks are taken out and surface dried.

(c) Each brick is placed on the compression testing machine and the load on the brick is gradually increased until the brick fails. The failure load of each brick is found out.

(d) Average failure load of the 3 bricks is the compressive strength of the bricks.

Requirement standards

1. Country Bricks → 3.5 to 5.0 N/mm^2
2. II Class bricks → 5.0 to 7.5 N/mm^2
3. I Class bricks → 7.5 to 12.5 N/mm^2

3.3.7 Manufacture of Bricks

The following are the four processes involved in the manufacture of bricks.

1. Preparation of brick earth
2. Moulding of bricks
3. Drying of bricks
4. Burning of bricks

1. Preparation of Brick Earth

Preparation of brick earth involves the following operations.

(i) Removal of loose soil
(ii) Digging, Spreading and Cleaning
(iii) Weathering
(iv) Blending
(v) Tempering

(i) Removal of loose soil The top layer of the loose soil about 20cm depth contains lot of impurities and hence it should be taken out and thrown away.

(ii) Digging, spreading and cleaning The earth is then dug out from the ground. This earth is spread into heaps about 60 cm to 120 cm height. All the undesirable matters like stones, vegetable matter etc. are removed. Lumps of clay should be converted into powder form.

(iii) Weathering The earth is then exposed to atmosphere for softening. The period of exposure varies from weeks to full season.

(iv) Blending The clay is then mixed with suitable ingredients. It is carried out by taking a small portion of clay every time and by turning it up and down in vertical direction.

(v) Tempering This is done to make the whole mass of clay homogenous and plastic. Required water is added to clay and the whole mass is kneaded under the feet of men or cattle.

When bricks are manufactured on a large scale, tempering is usually done in a pug mill. A pug mill consists of a conical iron tub with cover at its top. A vertical shaft with horizontal arms is provided at the centre of iron tub. Several cutting blades are attached to this horizontal arm. The clay with water is put inside the mill and the vertical shaft is rotated by bullocks or stream, diesel or electric power. Due to the action of the horizontal arms the clay is thoroughly mixed and tempered.

2. *Moulding of Bricks*

The tempered clay is then sent for the next operation of moulding. There are two methods of moulding.

(i) Hand moulding
(ii) Machine moulding

1. Hand Moulding This is done by a mould which is a rectangular box with open at top and bottom. It may be of wood or steel.

Following are the ways of hand moulding:

(a) Ground moulding
(b) Table moulding

(a) *Ground moulding* First a small portion of ground is cleaned and leveled. Fine sand is sprinkled over it. Moulding is started from one end of the ground. Mould is dipped in water and kept on the ground and clay is pressed by hand nicely so that all is again dipped in water and it is placed just near the previous brick to prepare another brick. Process is repeated till the ground is covered with bricks. A mark of depth about 10 mm to 20 mm is placed on raw brick by a pallet during moulding. This mark is called as frog. After the bricks become sufficiently dry, they are sent for the next process of drying.

(b) *Table moulding* This should be done by an experienced supervisor. The moulder stands near a table of size about 2 m × 1m. Clay, mould water pots, stock board, strikes and pallet boards are placed on this table. Bricks are moulded on the table and sent for the next process of drying.

2. *Machine moulding* When bricks are manufactured in huge quantity at the same spot then moulding is done by machines. These machines contain a rectangular opening of size equal to the length and width of the brick. The Tampered clay is placed in the machine and as it comes out through the opening under pressure it is cut into strips by wire fixed in frames. Arrangement is made in such a way that strips of thickness equal to that of the brick are obtained.

   The machine moulded bricks have sharp edges and corners, smooth external surface and uniform texture.

3. Drying of Bricks

After the bricks are moulded they are dried. This is done on specially prepared drying yards. Bricks are stacked in the yard with 8 to 10 bricks in each row. Bricks are dried for a period of 5 to 12 days.

During drying it must be protected from wind, rain and direct sun. Sometimes, bricks, are dried artificially by hot gases from kiln. But there is change of warping of bricks in case of artificial drying. After drying, the bricks are sent for the next operation of burning.

4. Burning of Bricks

Burning imparts hardness and strength to bricks and makes them dense and durable. It must be done carefully and properly because underburnt bricks remain soft and hence cannot carry loads and overburnt bricks become brittle and hence, break easily. Burning of bricks is done either in clamp or in kilns.

3.4 STONES **[May, June 2011]**

Building stones are obtained from rocks. It is essential to have some knowledge about rocks in order to study the properties of stones. Rocks are mainly classified into igneous rocks, sedimentary rocks and metamorphic rocks. Igneous rocks are formed by the cooling of the molten material from beneath the earth's surface. Stones from these rocks are said to be harder. Granite which is widely used in building constructions is a good example.

Sedimentary rocks are formed by the deposition of weathering products on existing rocks. Deposits are in layers and when load is applied along the layers these rocks easily split.

Metamorphic rocks are formed by the change in character of the pre-existing rocks. These will be hard if the basic rock is an igneous rock.

3.4.1 Qualities of Good Stone [Nov, Dec 2009, 2011; May, June 2011, 2013; Apr, May 2015]

1. The crushing strength of stone should be greater than 100 N/mm^2. All igneous rocks have a strength around 100 N/mm^2 and some of the metamorphic rocks also satisfy this requirement. Sedimentary rocks have a lower strength.
2. Stones must be decent in appearance and be of uniform colour. Light coloured stones resist weathering action in a better way and hence preferred.
3. Stones must be durable. For the stones to be durable, their natural bed must be perpendicular to the direction of pressure.
4. Stones should be such that these can be easily carved and dressed. This property is opposed to strength and hardness but this depends upon the situation in which the stone is used.
5. For a good building stone its fracture should be sharp and clear.
6. If the stone is to be used in road work, it should be hard enough to resist wear and tear.
7. A good building stone must have a wear less than 3 per cent. If it is equal to 3 per cent, it is just tolerable while if it is more than 3 per cent it is not satisfactory.
8. Stones must be fire resistant, i.e., these must retain their shape when a fire occurs. Limestone resists fire up to about 800°C. Sandstones can resist fire in a better way. Argillaceous stones are poor in strength, but resist fire to some extent.
9. A good stone should not contain quarry sap which is nothing but moisture present in the stones.
10. A good building stone must have a specific gravity greater than 2.7.
11. A good stone must have a compact, fine, crystalline structure, strong and durable.
12. A good stone should not absorb water more than 0.6 per cent by weight. It must be capable of withstanding effects of atmosphere.
13. A good building stone must be acid resistant and free from any soluble matter.

Stones with exposed faces are acted upon by various atmospheric agencies such as wind, frost, living organisms, alternate wetness and drying, movement of chemicals and rain water. Stones can be prevented from the effects of these agencies if preserved properly. Coal tar, linseed oil, paint, paraffin, a solution of alum and soap, and a solution of baryta are some of the commonly used preservatives.

3.4.2 Uses of Stones [Nov, Dec 2011]

Stones are used

1. In the construction of buildings from the very ancient times.
2. For foundations, walls, columns, lintels, arches, roofs, floors, damp proof courses, etc.
3. For facing works in brick masonry to give a massive appearance.
4. Since stones are hard, these can be used for pavements.
5. As a basic material for concrete, moorum of roads, calcareous cements, etc.
6. As ballast in railways, flux in blast furnaces, blocks in construction of bridges, piers, abutments, retaining walls, light houses, dams, etc.

3.4.3 Quarrying of Stones

Quarrying is the process of extracting stone blocks from existing rocks. It is done at some depth below the top surface of rock where the effects of weathering are not found. Quarrying of soft and hard rocks is done by the following methods:

1. Digging, heating or wedging: In soft rocks like limestone and marble, stones are obtained by digging, heating or wedging using hand tools, namely, pick-axes, hammers, chisels, etc.
2. Blasting: In hard and dense rocks, stones are obtained by blasting using explosives.

3.4.4 Dressing of Stones

Stones obtained after quarrying have rough surfaces and are irregular in shape and size. Dressing is the process of cutting the stones to a regular shape and size and the required surface finish. The purposes of dressing are:

1. To prepare the stones for a suitable size for any handling and transport.
2. To prepare the stones into a regular shape and pleasing appearance, with neat horizontal and vertical mortar joints between the adjacent stones.
3. To make hammer-dressed surface, tooled surface, polished surface, rubbed surface or cut-stone surface to suit a particular stone masonry.
4. To secure proper bedding in stone masonry.

3.4.5 Testing of Building Stones

To determine the suitability of stones for construction work, the following tests are conducted:

1. *Hardness test* Hardness of a stone is tested by a pen knife which will not be able to produce a scratch on a hard stone. Hardness number is determined using Mohr's scale of hardness.

2. *Impact Test* Impact test is carried out on an Impact Testing Machine to determine the toughness of a stone. In this test, a cylinder of 25 mm diameter and 25 mm height is taken out from the sample of the stone. A steel hammer of 2 kg weight is allowed to fall axially on the cylinder from 1 cm height for the first flow, 2 cm height for the second blow, 3 cm height for the third flow, and so on. The blow at which the specimen breaks is noted. If it is the n^{th} blow, n represents the Toughness Index of the stone.
3. *Test for crushing strength* In this test, a cube of sample stone of size 40 mm × 40 mm × 40 mm is tested in a compression Testing Machine. The rate of axial loading on the cube is 13.7 N/mm^2/ minute. The maximum load at which the stone crushes is noted. Crushing strength of the stone per unit area is the maximum load at which its sample crushes or fails divided by the area of the bearing face of the specimen.

   That is, Crushing Strength of stone $= \dfrac{\text{Maximum load at failure}}{\text{Area of bearing face}}$
4. *Fire resistance test* The stone, which is free from calcium carbonate, can resist fire. The presence of calcium carbonate in the stone can be detected by dropping a few drops of dilute sulphuric Acid which will produce bubbles.
5. *Electrical Resistance/ Water Absorption Test* As the electrical resistance of a wet stone is less, the stone should be non-absorbent. In this test, a stone of known weight is immersed in water for 24 hours. Then, it is weighed again. Percentage absorption of water by weight after 24 hours = (Increase in weight/ Original weight of the stone).
6. *Attrition test/Abrasion Test* Attrition test is carried out to determine the percentage of wear of stones used for the construction of road. It is carried out in Deval's Attrition Testing Machine.

   In this test, some known weight of stone pieces are taken and put in the Deval's Attrition Test Cylinder. The cylinder is rotated about its horizontal axis at the rate of 30 rpm for 5 hours. Then, the contents of the cylinder are sieved. The quantity of material retained on the sieve is weighted. Percentage Wear = (Loss in Weight/ Initial Weight) × 100.
7. *Acid Test* In this test, a specimen stone is kept for 1 week in the solution of sulphuric acid and hydrochloric acid. The corners of stones with high alkaline content turn roundish and loose particles will get deposited on its surface. Such types of stones are unsuitable for smoky atmosphere.
8. *Smith's test* This test indicates the presence of earthly matter in the stone. In this test, the sample of the stone is broken into small pieces and put into a test tube containing clear water. The test tube is then shaken vigorously. The directly colour will directly show the presence of argillaceous matter.
9. *Crystallization test* This test determines the durability or weathering quality of a stone. In this test, a sample of stone is immersed in the solution of sodium sulphate and dried in hot air. The process of wetting and drying is carried out for 2 hours.

The difference in weight, if any, is recorded. Little difference in weight indicates durability and good weathering quality of the stone.

10. *Microscopic test* This is a Geologist's test. In this test, the sample of stone is subjected to microscopic examination to study the following properties:
    - Mineral constitution
    - Texture of stone
    - Average grain size
    - Nature of cementing material
    - Presence of pores, fissures and veins.
11. *Freezing and thawing test* In this test, the specimen stone is kept in water for 34 hours. It is then placed in a freezing mixture at –12° C for 24 hours. It is then thawed (warmed) to atmospheric temperature. The procedure is repeated several times and the behaviour of the stone is studied.

3.4.6 Types of Building Stones and their Uses [May, June 2013]

1. *Granite* It is obtained from igneous rocks. It is hard, durable and available in different colours. It is highly resistant to weathering and has good crushing strength. It can take mirror-like polish.

   Uses: Granite is used for the construction of walls, columns and bridge piers. Its is used for steps, sills and facing works. Also, it is used vas ballast for road metal, rail metal, rail track and coarse aggregate for concrete. It is unsuitable for carving.
2. *Basalt and Trap* Basalt and Trap are also quarried from igneous rocks. These are hard, tough and durable and available in different colours.

   Uses: Basalt and Trap are used for constructing masonry floors, ornamental or decorative works and as road metal.
3. *Chalk* Chalk belongs to sedimentary variety. It is pure white stone, soft and easy to form powder.

   Uses: Chalk is used in preparing glazer's putty and also as colouring material in the manufacture of Portland cement.
4. *Limestone* It is derived from sedimentary rocks. It is easy to work. It consists of a high percentage of calcium carbonate.

   Uses: Limestone is used for the manufacture of cement. It is also used for floors, steps, walls and as road metal.
5. *Sandstone* It belongs to sedimentary variety. Its structure shows sandy grains. It is easy to work and dress. It is available in different colours. Its strength is low.

   Uses: It is used for different building works like facing works, carving, steps, walls, columns and as road metal.
6. *Laterite* It is derived from metamorphic rocks. It is sandy clay stone. It is porous and soft. It can easily be quarried in blocks. It contains high percentage of iron oxide.

Uses It is used for wall construction, rough stone masonry work and as road metal.

7. *Gneiss* Gneiss is metamorphic in nature. It is easy to work and splits into thin slabs.

   Uses It is used as thin slabs for flooring, street paving, rough stone masonry work. etc.

8. *Marble* Marble is metamorphic. It can take good polish. It can be easily cut with saw and carved. It is available in different colours.

   Uses Marble is used for flooring in the form of slabs, wall lining, facing work, steps, columns, etc. It is used for interior decoration and such ornamental works. Taj mahal is built fully of white marbles.

9. *Gravel* It is available in river beds in the form of pebbles of any kind of stone.

   Uses It is used for surfacing road. It is also used in concrete.

10. *Slate* Slate is metamorphic. It is black in colour and can be split easily.

    Uses It is used as roofing tiles, paving works and as damp-proof course in buildings.

11. *Quartzite* It is metamorphic. It is hard, durable, brittle and crystalline. It is difficult to work.

    Uses It is used in rubble masonry, concrete aggregate, retaining walls and as road metal.

3.5 CEMENT **[Nov, Dec 2009]**

Cement is obtained by burning at a very high temperature a mixture of calcareous and argillaceous materials. The calcined product is known as *clinker*. A small quantity of gypsum is added to the clinker and is pulverised into very fine powder known as cement. On setting, cement resembles a variety of sandstone found in Portland in England and is, therefore, called Portland cement.

3.5.1 Good Qualities of Cement **[May, June 2010, 2013, 2014]**

1. The colour should be uniform.
2. Cement should be uniform when touched. Cement should be cool when felt with hand. If a small quantity of cement is thrown into a bucket of water, it should sink.
3. Cement should be free from lumps.
4. Cement mortar at the age of three days should have a compressive strength of 11.5 N/mm^2 and tensile strength of 2 N/mm^2. Also, at the age of seven days, compressive strength should not be less than 17.5 N/mm^2 and tensile strength should not be less than 2.5 N/mm^2.

5. In cement, the ratio of percentage of alumina to that of iron oxide should not be less than 0.66.
6. When ignited, cement should not loose more than 4 per cent of its weight.
7. The total sulphur content of cement should not be greater than 2.75 per cent.
8. The weight of insoluble residue in cement should not be greater than 1.5 per cent.
9. Weight of magnesia in cement should not exceed 5 per cent.
10. The specific surface of cement as found from the fineness test should not be less than 2250 mm^2/gm.
11. The initial setting time of cement should not be less than 30 minutes and the final setting time shall be around 10 hours.
12. The expansion of cement should not be greater than 10 mm when soundness test is conducted.

3.5.2 Uses of Cement **[May, June 2010; Nov, Dec 2011, 2013, 2014]**

1. Cement mortar, a mixture of cement and sand, is used for masonry work, plastering, pointing and in joints of pipes, drains, etc.
2. Cement is the binding material in concrete used for laying floors, roofs and constructing lintels, beams, weather sheds, stairs, pillars, etc.
3. Construction of important engineering structures, such as bridges, culverts, dams, tunnels, storage reservoirs, light houses and docks needs cement.
4. The manufacture of precast piles, pipes, garden seats, artistically designed urns, flower pots, dust bins, fencing post, etc., requires cement.
5. For underwater construction, quick setting cement is used. Rapid hardening cement is used for structures requiring early strength.
6. White and coloured cements are used for imparting coloured finishes to the floors, panels and exterior surfaces of buildings.
7. Expansive cements, which expands while setting, can be used in repair works of cracks.

3.5.3 Types of Cement **[Nov, Dec 2009; May, June 2010]**

By changing the chemical composition and by using different raw materials and additives, many types of cements can be manufactured to cater to the need of the construction industry for specific purposes. Different types of cements are classified as Portland and Non-Portland cement.

1. Rapid-hardening Cement This cement is similar to the ordinary portland cement. As the name suggests, it develops strength rapidly. The rapid rate of strength development is attributed to the higher fineness of grinding. This cement is used where high strength is required instantly in initial stages. For example, repair works, early removal of formwork, etc.

2. Sulphate-resisting Cement Ordinary Portland cement has less resistance to the attacks of sulphates. This type of cement with higher silicate content is effective in fighting back the attacks of sulphates. This is used for the construction of sewage treatment works, marine structures and foundations in soils having large sulphate content.

3. Low-heat Cement This cement hardens slowly but produces less heat than the other cements while reacting with water. This can be used in mass concreting works like construction of dams, etc.

4. Quick-setting Cement This cement sets very quickly. This is due to the reduction of gypsum content in the normal Portland cement. It is used for underwater construction and also for grouting operation.

5. Portland pozzolana Cement Pozzolana is a siliceous material. Portland pozzolana cement is produced by grinding Portland cement clinker and pozzolana with gypsum. It produces less heat of hydration and offers greater resistance to the attack of aggressive water.

6. High-alumina Cement This cement generates high heat while reacting with water and causes high early strength development. So this cement can be used for generating high early strength in cold climates.

7. Air-entraining Cement This cement is produced by mixing a small amount of an air-entraining agent with ordinary Portland cement. By adding this, the properties of concrete can be changed and it also increases the frost resistance of hardened concrete.

8. Masonry Cement This cement has great plasticity, workability and water retentivity as compared with ordinary Portland cement. This is used for masonry constructions in making mortars and plasters.

9. Expansive Cement This cement produces an expansion in concrete during curing. As a result of expansion, cracks due to shrinkage of concrete are avoided. So, this can be used for filling the cracks by grouting and also to overcome cracks formation in reinforced cement concrete structures.

10. Hydrophobic Cement This is a water-repellent cement and is of great utility when the cement has to be stored for longer duration in wet climatic conditions. This cement also improves the workability of concrete.

11. Coloured Cement Coloured cement consists of ordinary portland cement with 5 to 10 per cent of pigment for colouring. This is used for aesthetic purposes.

12. White Cement The colour of this cement is white and it has the same properties of ordinary Portland cement. This can be used for architectural purposes and for manufacturing coloured concrete, flooring tiles, etc.

13. High-strength Cement Certain special works require high strength concrete. To improve the strength a higher content of C_3S and higher fineness are incorporated in ordinary Portland cement. This cement can be used for railway sleepers, prestressed concrete, precast concrete and air-field works.

3.5.4 Mortar

1. Definition The term mortar is used to indicate a paste prepared by adding required quantity of water to a mixture of binding material (cement or lime) and fine aggregate (sand). The above two components of mortar, namely, the binding material and fine aggregate are sometimes referred to as the matrix and adulterant respectively. The matrix binds the particles of the adulterant. The durability, quality and strength of mortar will mainly depend on the quantity and quality of the matrix. The combined effect of the two components of mortar is that the mass is able to bind the bricks or stones firmly.

1.1 Grade of Cement

(a) M33 Grade Cement M refers to the mix, 33 refers the compressive strength of 15 × 15 × 15 cm size concrete cube at the age of 28 days—used for plastering work.

(b) M43 Grade Cement M refers to the mix, 43 refers the compressive strength of 15 × 15 × 15 cm size concrete cube at the age of 28 days—used for bricks or stone masonry walls constructions.

(c) M53 Grade Cement M refers to the mix, 53 refers the compressive strength of 15 × 15 × 15 cm size concrete cube at the age of 28 days—used for concreting works.

2. Types of Mortars The mortars are classified on the basis of the following:

(a) Bulk density
(b) Type of binding material
(c) Nature of application
(d) Special mortars

(a) Bulk density According to the bulk density of mortar in dry state, there are the following two types of mortars.

(i) Heavy mortars The mortars having bulk density of 15 kN/m^3 or more are known as heavy mortars and they are prepared from heavy quartzs or other sands.

(ii) Lightweight mortars The mortars having bulk density less than 15 kN/m^3 are known as lightweight mortars and they are prepared from light porous sands, pumice and other fine aggregates.

(b) Type of binding material The type of binding material used for a mortar is according to several factors such as expected working conditions, hardening temperature, moisture conditions, etc. According to the type of binding material, the mortars are classified into the following five categories.

(i) Lime mortar In this type of mortar, lime is used as binding material. The lime may be fat lime or hydraulic lime. The fat lime shrinks to a great extent and hence, it requires sand to the extent of about 2 to 3 times its own volume. The lime should be slaked before use. This mortar is unsuitable for water-logged areas or in damp situations.

The lime mortar has a high plasticity and it can be placed easily. It possesses good cohesiveness with other surfaces and shrinks very little. It is sufficiently durable, but it hardens slowly. It is generally used for lightly loaded above-ground parts of buildings.

(ii) Surkhi mortar This type of mortar is prepared by using only *surkhi* instead of sand or by replacing half of sand in case of fat lime mortar. The powder of *surkhi* should be fine enough to pass BIS No.9 sieve and the residue should not be more than 10 per cent by weight.

Surkhi mortar is used for ordinary masonry work of all kinds in foundation and superstructure. But it cannot be used for plastering or pointing since *surkhi* is likely to disintegrate after some time.

(iii) Cement mortar In this type of mortar, cement is used as binding material. Depending upon the strength required and importance of work, the proportion of cement to sand by volume varies from 1:2 to 1:6 or more. It should be noted that *surkhi* and cinder are not chemically inert substances and hence, they cannot be used as adulterants with matrix as cement. Thus, only sand can be used to form cement mortar. The proportion of cement with respect to sand should be determined with due regards to the specified durability and working conditions. The cement mortar is used where a mortar of high strength and water-resisting properties is required such as underground constructions, water saturated soils, etc.

(iv) Gauged mortar To improve the quality of lime mortar and to achieve early strength, cement is sometimes added to it. This process is known as gauging. It makes lime mortar economical, strong and dense. The usual proportion of cement to lime by volume is about 1:6 to 1:8. It is also known as a composite mortar or lime- cement mortar and it can also be formed by the combination of cement and clay. This mortar may be used for bedding and for thick brick walls.

(v) Gypsum mortar These mortars are prepared from gypsum binding materials such as building gypsum and anhydrite binding materials.

(c) Nature of application According to the nature of application, the mortars are classified into the following two categories.

(i) Bricklaying mortars The mortars for bricklaying are intended to be used for brickwork and walls. Depending upon the working conditions and type of construction, the composition of masonry mortars with respect to the kind of binding material is decided.

(ii) Finishing mortars These mortars include common plastering work and mortars for developing architectural or ornamental effects. The cement or lime is generally used as binding material for ordinary plastering mortar. For decorative finishing, the mortars are composed of suitable materials with due consideration of mobility, water retention, resistance to atmospheric actions, etc.

(d) Special mortars Following are the various types of special mortars which are used for certain conditions.

(i) Fire-resistant mortar This mortar is prepared by adding aluminous cement to the finely crushed powder of fire-bricks. The usual proportion is one part of aluminous cement to two parts of powder of fire-bricks. This mortar is fire-resistant and is therefore used with fire-bricks, for lining furnaces, fire places, ovens, etc.

(ii) Lightweight mortar This mortar is prepared by adding materials such as saw dust, wood powder, etc. to the lime mortar or cement mortar. Other materials which may be added are asbestos fibres, jute fibres, coir, etc. This mortar is used for sound-proof and heat-proof construction.

(iii) Packing mortar To pack oil wells, special mortars possessing the properties of high homogeneity, water resistance, predetermined setting time, ability to form solidwater proof plugs in cracks and voids of rocks, resistance to subsoil water pressure, etc. have to be formed. The varieties of packing mortars include cement-sand, cement-loam and cement-sand-loam. The composition of packing mortar is decided by taking into consideration the hydrogeologic conditions, packing methods and type of timbering.

(iv) Sound-absorbing mortar To reduce the noise level, the sound-absorbing plaster is formed with the help of sound-absorbing mortar. The bulk density of such a mortar varies from 6 to 12 kN/m^3 and the binding materials employed in its composition may be Portland cement, lime, gypsum, slag, etc. The aggregates are selected from lightweight porous materials such as pumice, cinders, etc.

(v) X-ray shielding mortar This type of mortar is used for providing the plastering coat to walls and ceiling of X-ray cabinets. It is a heavy type of mortar with bulk density over 22 kN/m^3. The aggregates are obtained from heavy rocks and suitable Admixtures are added to enhance the protective property of such a mortar.

3. Properties of Mortar Following are the properties of a good mortar:

1. It should be capable of developing good adhesion with the building units such as bricks, stones, etc.
2. It should be capable of developing the designed stresses.
3. It should be capable of resisting penetration of rain water.
4. It should be cheap.
5. It should be durable.
6. It should be easily workable.
7. It should not affect the durability of materials with which it comes into contact.
8. It should set quickly for speedy construction.
9. The joints formed by mortar should not develop cracks and they should be able to maintain their appearance for a sufficiently long period.

4. Uses of Mortar Following are the uses of mortar:

1. To bind the building units such as bricks, stones, etc. into a solid mass.
2. To carry out pointing and plaster work on exposed surfaces of masonry.
3. To form an even and soft bedding layer for building units.
4. To form joints of pipes.
5. To improve the general appearance of a structure.
6. To prepare moulds for coping, corbles, cornice, etc.
7. To serve as a matrix or cavity to hold coarse aggregates, etc.
8. To distribute uniformly the super incumbent weight from the upper layer to the lower layer of bricks or stones.
9. To hide the open joints of brickwork and stonework.
10. To fill up the cracks detected in the structure during maintenance process, etc.

5. Selection of Mortar Depending upon the nature of civil engineering work, suitable type of mortar should be selected or recommended. Table 3.1 shows the types of mortars to be used for various civil engineering constructions.

Table 3.1 Selection of mortars

S.No.	*Nature of work*	*Type of mortar*
1.	Construction work in waterlogged areas and exposed positions	Cement or lime mortar in the proportion 1 :3, lime being eminently hydraulic lime
2.	Damp-proof courses and cement concrete roads	Cement mortar in the proportion 1:2
3.	General RCC work such as lintels, pillars, slabs, stairs, etc.	Cement mortar in the proportion 1:3, the concrete mix being 1:2:4
4.	Internal walls and surfaces of less importance	Lime cinder mortar proportion, being 1:3. Sand is replaced by ashes or cinder
5.	Mortar for laying fire-bricks	Fire-resisting mortar consisting of 1 part of aluminous cement to 2 parts of finely crushed powder of fire-bricks.
6.	Partition walls and parapet walls	Cement mortar in the proportion 1:3 or lime mortar proportion 1:1. Lime should be moderately hydraulic lime
7.	Plaster work	Cement mortar in the proportion 1:3 to 1:4 or lime mortar proportion 1:2
8.	Pointing work	Cement mortar in the proportion 1:1 to 1:2
9.	Reinforced brickwork	Cement mortar in the proportion 1:3
10.	Stone masonry with best varieties of stones	Lime mortar in the proportion 1:2, lime being eminently hydraulic lime
11.	Stone masonry with ordinary stones, brickwork, foundations, etc.	Lime mortar in the proportion 1:2 or cement mortar proportion 1:6. Lime should be eminently hydraulic lime or moderately hydraulic lime
12.	Thin joints in brickwork	Lime mortar in the proportion 1:3, lime being fat lime

3.5.5 Sand **[May, June 2012; Nov, Dec 2012]**

1. Classification of sand According to the nature of source, sand is classified into two groups:

(a) Natural Sand (b) Artificial Sand

(a) Natural sand Is the one which is carried by the river water and is quarried from the river bed, when the river becomes dry.

(b) Artificial sand Is the one which is the outcome of crushing and breaking stones into different sizes of stone aggregates in a stone crushing plant (or) crushed gravel sand.

2. Qualities of Good Sand **[May, June 2012, 2014; Nov, Dec 2012]**

(a) Sand should be clean, hard and durable and preferably dry.

(b) It should be free from mica, chemical salts, organic and inorganic impurities and outer foreign matters.

(c) It should preferably be free from, clay, silt and fine dust. In case if the presence of them is unavoidable, they should not be present by more than 5% by weight (or 7% by volume)

(d) Sand particles should be well graded and shall have sizes ranging from (150 micron) 0.15 m.m to 4.75 m.m.

(e) The fineness modulus of sand shall be from 1.6 to 3.5.

3. Uses of Sand **[May, June 2012, 2014; Nov, Dec 2012]**

(a) It is used for making mortar and concrete

(b) It is used for filling in the basement of buildings to receive the flooring concrete.

(c) It is used as a binding material on the top of bituminous road.

(d) It imparts mechanical strength to the mortar and prevents shrinkage and cracking of mortar while setting.

(e) It forms major portion of mortar and reduces the cost of mortar.

(f) It is mixed with expensive clay soils to stabilise them and prevent cracking of clay soils due to seasonal moisture changes.

4. Tests on Sand The following tests are conducted to find out the suitability of sand.

(a) Sieve analysis and fineness modulus test

(b) Test for bulkage of sand

(c) Test for silt content

(a) Sieve analysis and fineness modulus test The sand is sieved through 1. S. Sieves 4.75 mm 2.36 mm., 1.18 mm, 600 micron, 300 micron and 150 micron sieves and percentage retained in each sieve is found out.

Fineness modulus of sand = sum of the percentages retained in each sieve divide by 100.

Requirement A fineness modulus of 1.6 to 2.0 for sand for plastering mortar and a fineness modulus of 2.5 to 3.5 for sand for concrete and a fineness modulus of 2.0 to 3.0 for sand for masonry mortar may be sufficient.

(b) Test for bulkage of sand: bulking of sand The volume of dry sand will increase due to the presence of water in the sand up to about 25% of water content and therafter it will decrease and become equal to its dry volume, when it is saturated with water. This increase in volume of sand is know as bulking of sand.

River sand will generally be wet and its volume will be more than the dry volume. Hence, it is necessary to known the bulking of sand to allow for its increase in volume in the volume batching of concrete and mortar. The increase is volume of sand is found out from the test for bulkage of sand.

Test for bulkage A small quantity of wet sand is poured into a glass measuring jar and rammed by a small rod of dia 6 mm. and level of sand is noted (say H1). Now water is poured into the cylinder until the sand is submerged and the glass jar is well shaken and now the level of sand is noted. (say H2). H2 will be less than H1 and sand is saturated when it is submerged.

$$\text{Percentage bulkage of sand} = \frac{(H1 - H2)}{H2} \times 100$$

(c) Test of silt content A small quantity of sand is poured into a glass measuring jar. Now water is poured until sand is well submerged in water. The glass jar is now shaken several times so that the silt and dust layer floats at the top of sand layer. The level of sand layer (excluding silt layer) is noted (say H2). The top level of silt layer above sand is noted. (say H1).

$$\text{The percentage of silt by volume} = \frac{(H1 - H2)}{H2} \times 100$$

3.6 CEMENT CONCRETE [May, June 2012; Apr, May 2015]

Cement concrete is a mixture of cement, sand, crushed rock and water which when placed in the skeleton of forms and allowed to cure, becomes hard such as stone. Concrete has attained the status of a major building material in all branches of modern construction and hence it is necessary to know the properties and uses of concrete.

3.6.1 Properties of Concrete [May, June 2009, 2014]

1. It has a high compressive strength and its strength depends on the proportion in which cement, sand, stones and water are mixed.
2. It is free from corrosion and there is no appreciable effect of atmospheric agents on it.
3. It hardens with age and the process of hardening continues for a long time after the concrete has attained sufficient strength.
4. As it is weak in tension, steel reinforcement is placed in it to take up the tensile stresses. This is termed as 'Reinforced Cement Concrete'.
5. It shrinks in the initial stage due to loss of water through forms. The shrinkage of cement concrete occurs as it hardens.
6. It has a tendency to be porous. This is due to the presence of voids which are formed during and after its placing.
7. It forms a hard surface, capable of resisting abrasion.

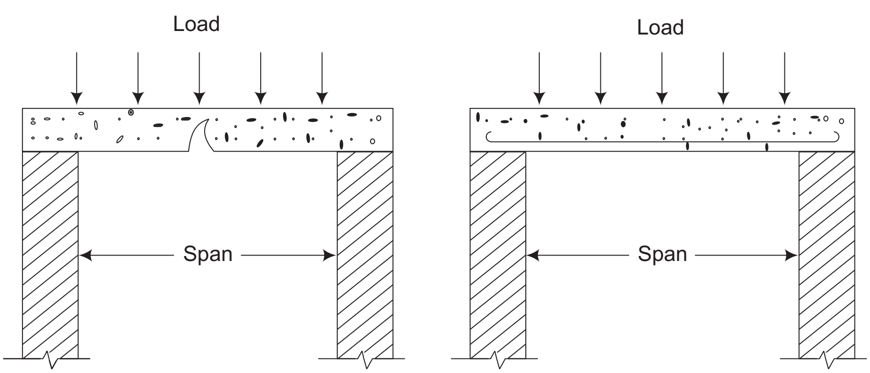
3.6.2 Uses of Concrete [May, June 2009, 2014]

1. Concrete can be made impermeable by using hydrophobic cement. This is used for the construction of RCC flat-roof slabs.
2. Coloured concrete is used for ornamental finishes in buildings, park lanes, separating lines of road surfaces, underground pedestrian crossings, etc.
3. Light weight concrete is used in multi-storeyed constructions.

4. No-fines concrete is one in which sand is eliminated. This can be used for *cast-in-situ* external load bearing walls of single and multi-storey houses, retaining walls, damp-proofing material, etc.
5. Concrete is mainly used in floors, roof slabs, columns, beams, lintels, foundations and in precast constructions.
6. It is used in massive structures, such as dams and bridges.
7. Concrete is used in the construction of roads, runways, playgrounds, water tanks and chimneys.
8. It is used in the construction of sleepers in railways.
9. Prestressed concrete is a relatively new type of concrete which is used in many constructions particularly in the construction of bridges.
10. Concrete trusses are also used in factory constructions.
11. Concrete is used in the construction of bunkers, silos, etc.
12. It finds a place in the construction of nuclear reactors because of its high shielding capacity for the radioactivity.
13. Thin economical shell construction are possible with the use of concrete.

3.6.3 Reinforced Concrete

Plain concrete is very weak in tension and cannot be used in the construction of lintels, roof slabs, beams, etc. in which the bottom fibres of them are subjected to tensile stresses. Figure 3.1 explains how a loaded beam or a slab is subjected to a flexural action when it is laid over an opening known as span. The top portion is compressed while the bottom portion is stretched. As concrete withstands compression but not tension, steel rods are embedded in the bottom portion to withstand the tension. A combination of concrete and steel is known as reinforced cement concrete and is widely used in various situations.



(a) A plain concrete member subjected to flexure

(b) A reinforced concrete member subjected to flexure

Fig. 3.1 *Flexure action*

Reinforcing bars are available from 6–32 mm diameter and of 22 feet length. They may be of mild steel or Tor steel and may be plain or twisted.

3.6.4 Advantages of Reinforced Concrete [May, June 2012]

1. Reinforced concrete is a versatile building material and can be used for casting members of any shape.
2. It has good resistance to fire, temperature and weathering actions.
3. RCC construction is easy and fast.
4. The component materials used for preparing RCC are easily available
5. Monolithic construction is possible with the use of RCC. This increases the stability and rigidity of the structure.
6. RCC is tough and durable.
7. Maintenance of RCC construction is very cheap.
8. With proper cover, RCC can be made free from rusting and corrosion.

3.6.5 Types of Concrete [Nov, Dec 2014]

1. Light-weight concrete One of the disadvantages of normal concrete is the high self-weight which has a density of 2200 to 2600 kg/m^3. This heavy self-weight causes heavy load and increases the haulage and handling costs. In order to make an economical concrete, attempts were made in the past to reduce the self weight of concrete. As a result the light weight concrete was developed whose density varies from 300–1850 kg/m^3.

Advantages of light-weight concrete

(a) It has low density.
(b) It has low thermal conductivity.
(c) It lowers haulage and handling costs.

Types of light-weight concrete

(a) Light-weight aggregate concrete
(b) Aerated concrete
(c) No-fine concrete

(a) Light-weight aggregate concrete By replacing the usual mineral aggregate by cellular porous or light weight aggregate, light-weight aggregate concrete can be produced. Light-weight aggregate can be classified into two categories namely natural and artificial light-weight aggregate.

Natural light-weight aggregates are

(i) Pumice
(ii) Diatomite

(iii) Scoria
(iv) Volcanic cinders
(v) Saw dust
(vi) Rice husk

Artificial light-weight aggregates are

(i) Artificial cinders
(ii) Foamed slag
(iii) Bloated clay
(iv) Sintered flyash

(b) Aerated concrete By introducing gas or air bubbles in mortar, aerated concrete can be produced. This concrete is a mixture of water, cement and finely crushed sand with air or gas introducing agents.

There are several ways in which aerated concrete can be manufactured. One important way is by the formation of gas or air bubbles using finely powdered metal (usually aluminium powder). Chemical reaction takes place in the concrete and finally large quantity of hydrogen gas is liberated which gives the cellular structure.

(c) No-fine concrete By omitting sand fraction from the aggregate, no-fine concrete can be produced. This concrete is made up of only single-sized aggregate of size passing of 20 mm and retained on 10 mm coarse aggregate, cement and water. The single sized aggregate makes a good no-fine concrete, which in addition gives large voids and hence is light in weight. It also offers an architecturally attractive look.

Out of the three main groups of light-weight concrete, the light-weight aggregate concrete and aerated concrete are more often used than the no-fine concrete.

2. High-density concrete The concrete whose unit weight ranges from about 3360–3840 kg/m^3 and which is about 50 per cent higher than the unit weight of normal concrete is known as high-density concrete.

The high-density concrete is mainly used in the construction of radioactive shields. High-density concrete is made by using such a heavy-weight aggregate whose specific gravity is more than 3.5. The aggregates used in this type of concrete should be clean, strong, inert and relatively free from deleterious material. Normally barite, magnetite, lemonite are used to make high-density concrete. To produce high density and high strength concrete, it is necessary to control the water–cement ratio, correct admixture and vibrators for good compaction.

3. Polymer concrete Air voids and water voids are present in the conventional concrete due to improper compaction, high water-cement ratio and some other causes. Due to compaction, these voids are founed and the strength of the concrete is naturally reduced. There are number of methods available to reduce the air voids but none of these methods could really help to reduce the water voids. The impregnation of monomer and subsequent polymerisation is the latest technique adopted to reduce the inherent porosity of the concrete, to improve the strength and other properties of concrete. This type of concrete is known as polymer concrete.

Types of polymer concrete

1. Polymer Impregnated Concrete (PIC)
2. Polymer Cement Concrete (PCC)
3. Polymer Concrete
4. Partially impregnated and surface coated polymer concrete

The following are the monomers normally used in polymer concrete.

1. Methyl melthacrylate (MMA)
2. Styrene
3. Acrylonitrite
4. t-butyl styrene

Impregnation of these monomers improves the compressive strength, tensile strength, flexural strength of concrete and gives the concrete a high freeze thaw resistance and also high resistance to sulphate and acid attack.

Applications of polymer impregnated concrete

1. Prefabricated structural elements
2. Prestressed concrete
3. Marine works
4. Desalination plants
5. Nuclear power plants
6. Sewage works—pipes and disposal works
7. For water proofing of structures
8. Industrial applications

4. Fibre-reinforced concrete Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. Due to its poor tensile strength, internal microcracks are present in concrete which leads to brittle fracture. To improve the tensile strength of concrete one of the method used is that of the conventional reinforced steel bars and the other way is by introducing fibres in the concrete and thereby increasing the inherent tensile strength of concrete. In order to reduce the microcracks, addition of small, closely spaced and uniformly dispersed fibres are used. These fibres act as crack arrester and substantially improve its static and dynamic properties. This type of concrete is known as Fibre Reinforced Concrete (FRC). Some of the fibres used are steel fibres. polypropylene, nylons, asbestos, coir, glass and carbon. The property of concrete may vary depending upon the type, diameter, length and volume of fibres.

Steel fibre is one of the most commonly used fibre. Most of the times round fibres are used. The diameter of such fibres may vary from 0.25–0.75 mm. The use of steel fibres may improve the flexural, impact and fatigue strength of concrete.

Applications of fibre-reinforced concrete Normally, FRC are used in air field, road pavements, industrial floorings, bridge decks, canal lining, explosive resistant structures, refractory linings, etc. It can also be used in pre-cast products like pipes, boats, beams, staircase steps, wall panels, roof panels, manhole covers, etc.

3.6.6 Testing of Fresh and Hardened Concrete [Apr, May 2015]

1. Testing of fresh concrete Fresh concrete or plastic concrete is a freshly mixed material which can be moulded into any shape. The most important property of fresh concrete is its workability.

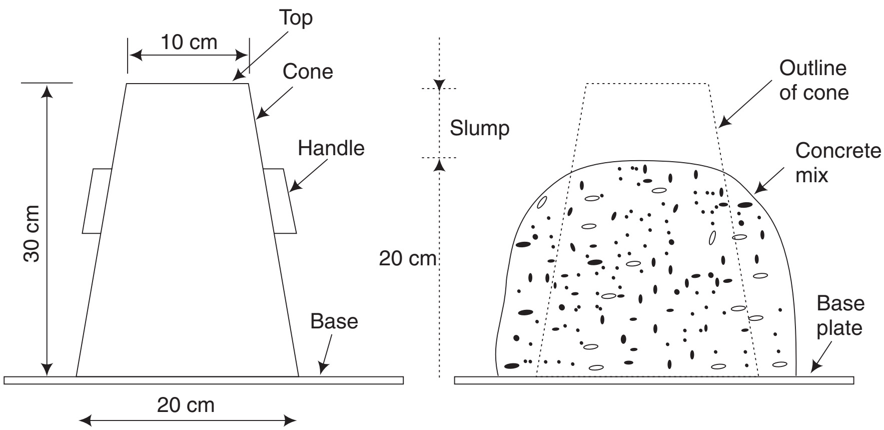
Workability The term *workability* is used to describe the ease or difficulty with which the concrete is handled, transported and placed between the forms with minimum loss of homogeneity. However, this gives a very loose description of this vital property of concrete which also depends on the means of compaction available. For instance, the workability suitable for mass concrete is not necessarily sufficient for thin, inaccessible or heavily reinforced sections. The compaction is achieved either by ramming or vibrating. The workability, as a physical property of concrete alone irrespective of a particular type of construction, can be defined as the amount of useful internal work necessary to produce full compaction.

If the concrete mixture is too wet, the coarse aggregates settle at the bottom of the concrete mass and the resulting concrete has a non-uniform composition. On the other hand, if the concrete mixture is too dry, it will be difficult to handle and place it in position. To correlate these two conflicting conditions proportions of various components of concrete mixture should be carefully decided. The important facts in connection with workability are as follows:

1. If more water is added to attain the required degree of workmanship, it results into concrete of low strength and poor durability.
2. If the strength of concrete is not to be affected then, the degree of workability can be obtained in following ways:
   (i) by slightly changing the proportions of fine and coarse aggregates, in case the concrete mixture is too wet.
   (ii) by adding a small quantity of water cement paste in the proportion of original mix, in case the concrete mixture is too dry.
3. A concrete mixture for one work may prove to be too stiff or too wet for another work. For instance, stiff concrete mixture will be required in case of vibrated concrete work while wet concrete mixture will be required for thin sections containing reinforcing bars.
4. The workability of concrete is affected mainly by water content, water–cement ratio and aggregate-cement ratio.
5. The workability of concrete is also affected by the grading, shape, texture and maximum size of the coarse aggregates used in the mixture.

In order to measure the workability of concrete mixture, various tests are developed. Tests such *as flow test* and *compaction test* are used mostly in laboratory. The *slump test,* which is commonly used in the field, is briefly described below. It should, however, be remembered that numerous attempts have been made to correlate workability with some easily determinable physical measurement. Although they may provide useful information within a range of variation in workability but none of these tests is fully satisfactory. At the same time, the slump test does not measure the workability of concrete. It is simply useful in detecting variations in the uniformity of a mix of given nominal proportions.

Slump test



(a) The cone filled with concrete paste (b) The settled paste after the cone is removed

Fig. 3.2 *Slump test*

The standard slump cone, as shown in Fig. 3.2 is placed on the ground. The operator holds the cone firmly by standing on the foot pieces. The cone is filled with about one-fourth portion and then rammed with a rod which is provided with bullet nose at the lower end. The diameter of the rod is 16 mm and its length is 60 mm. The strokes to be given for ramming vary from 20 to 30. The remaining portion of the cone is filled in with similar layers and then the top of concrete surface is struck off such that the cone is full of concrete. The cone is then gradually raised vertically and removed. The concrete is allowed to subside and then the height of concrete is measured. The slump of concrete is obtained by deducting the height of concrete after subsidence from 30 cm.

Table 3.2 shows the recommended slumps of concrete for various types of concrete and Table 3.3 shows the classification of concrete mixes on the basis of slump.

2. Testing of Hardened Concrete

1. Compressive Strength It may be defined as the maximum compressive load that can be taken by concrete per unit area. It has been shown that with special care and control, concrete can be made to bear loads as high as 80 N/mm^2 or even more. In practice, however, concrete with compressive strength between 10–50 N/mm^2 can be easily made on the site for common type of construction.

Table 3.2 Recommended slumps of concrete

S.No.	Type of concrete	Slump
1.	Concrete for road construction	20 to 40 mm
2.	Concrete for tops of curbs, parapets, piers, slabs and walls that are horizontal	40 to 50 mm
3.	Concrete for canal linings	70 to 80 mm
4.	Concrete for arch and side walls of tunnels	90 to 100 mm
5.	Normal RCC work	80 to 150 mm
6.	Mass concrete	25 to 50 mm
7.	Concrete to be vibrated	10 to 25 mrn

Table 3.3 Classification of concrete mixes

Slump	Nature of concrete mix
No slump	Stiff and extra stiff mix
From 10 to 30 mm	Poorly mobile mix
From 40 to 150 mm	Mobile mix
Over 150 mm	Cast mix

The compressive strength, also called the crushing strength, of concrete is determined by loading axially cube shaped (or cylindrical shaped) specimens made out of the concrete. The tests are carried out 3 days, 7 days and 28 days after the casting of the samples. It is the 28 days compressive strength which is taken as a standard value for concrete of a particular batch.

It has been observed that the compressive (crushing) strength of concrete is influenced by a very large number of factors. The most important of these factors are the following:

(i) Types of cement The composition, quality and age of the cement used in making concrete influences its strength. Thus, cement that has been stored for considerable time make concrete of lower strength despite all the other factors being the same. Cement with higher proportions of tri-calcium silicates produce concrete that show higher strengths, at least in earlier stages. Similarly, finer the particle size of the cement, higher is the ultimate compressive strength.

(ii) Nature of aggregates Sand and coarse aggregates are the other two essential components of concrete. A good bond between cement and the aggregate is possible only when the latter have sharp edges, clean surfaces and rough texture. Smooth and rounded aggregates result in comparatively poor bonds. Similarly, the aggregates used in concrete making should have in themselves, good compressive strength. For example, if chalk (very soft limestone) is used in making concrete instead of massive limestone, the resulting concrete will be weak in compressive strength because of the poor strength of the aggregate.

(iii) Water–cement ratio The compressive strength decreases, in general, with increasing water-cement ratio (other things being the same). Hence, when minimum water just to ensure complete hydration of the cement is used, the resulting concrete will give maximum compressive strength on proper compaction.

(iv) Curing conditions Great importance is attached to proper curing of concrete after its laying for obtaining maximum compressive strength. Incomplete curing and intermittent drying of concrete during the curing period may cause a loss in the compressive strength to the extent of 40 per cent or even more.

(v) Weather conditions The same concrete placed in different weather conditions like extremely cold, dry and hot, may develop different strength values. The cause is related to incomplete hydration of the cement in the concrete.

(vi) Admixtures Certain admixtures are added to the concrete at the mixing stage for some specific purposes. It has been observed that certain admixtures especially calcium chloride, increase the compressive strength. Some other admixtures (e.g. air entraining agents) however, affect the compressive strength adversely if proper controls are not maintained on water-cement ratio.

(vii) Methods of preparation Improper mixing of the concrete and careless transport and storing may result in poor strength despite best cement and aggregates used in it. It is the workmanship that determines the quality of the concrete work in ultimate analysis. A skilled worker can produce best concrete works despite some other deficiencies. An incompetent worker, however, may spoil the entire work despite being given the best designed concrete mix. The voids left in the concrete on compaction and curing have a profound influence on the strength of the concrete.

2. Tensile strength Plain concrete (without steel reinforcement) is quite weak in tensile strength which may vary from 1/8 to 1/20 of the ultimate compressive strength. It is primarily for this reason that steel bars (reinforcement) are introduced into the concrete at the laying stage so as to get a concrete which is very strong in compression as well as in tension. In plain concrete, tensile strength depends to a great extent on the same factors as the compressive strength does.

Tensile strength of concrete becomes an important property when it is to be used in road making and runways. It is determined by using indirect methods.

In one of such methods, it is derived from the *flexural strength tests.* In these tests, a beam of concrete is cast in standard dimensions depending upon the nominal size of the aggregate. The beam is properly cured and tested after 28 days. It is simply supported from below and equally loaded at its one-third span points from both supports till failure. The bending moments, obviously, induce compressive stresses at the top and tensile stresses at the bottom of beam. The beam fails in tension. Modulus of rupture or flexural strength is then calculated by using the usual beam formula given below:

$$fc = \frac{FL}{bd^2}$$

where

fc = flexural strength
F = maximum applied load
L = distance between supports
b = breadth
d = depth

In the second indirect method, called the *split cylinder method* as shown in Fig. 3.3, a cylinder of specified dimensions is made to fail under tension by applying compressive load across the diameter. This is termed as splitting tensile strength. The testing machine is adjusted to distribute the load along the entire length of the cylinder. From the load at failure, tensile strength is calculated using the following relationship.

$$f_t = \frac{2P}{\pi/d}$$

where

f_t = splitting tensile strength in N/mm^2
P = maximum applied load in N
l = length of the cylinder (mm)
d = diameter of the cylinder (mm)

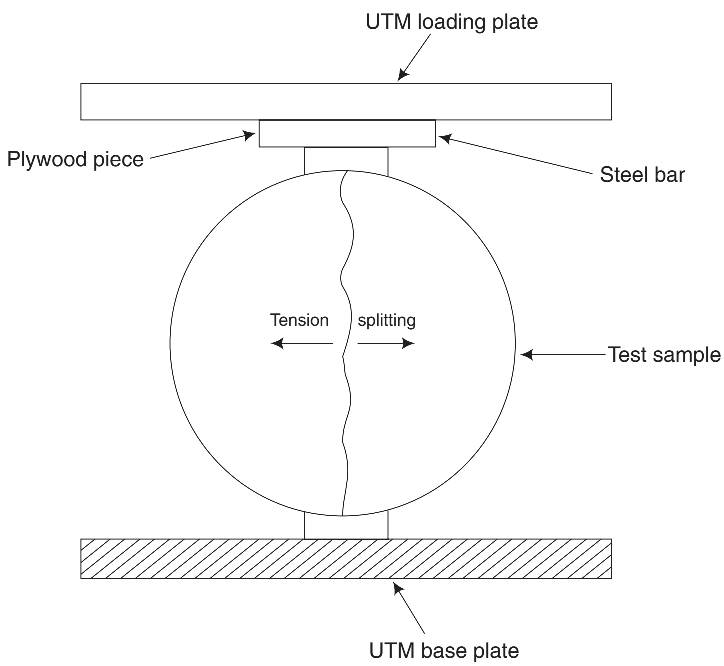


Fig. 3.3 *Split cylinder testing for tensile strength*

For approximate use, tensile strength of concrete may be taken between 10–12 per cent of its (cube) compressive strength.

3. Non-destructive tests for concrete Estimation of concrete or member strength is the most common requirement of *in-situ* investigations but unfortunately, none of the available methods can be used to provide a reliable value in every situation.

Non-destructive tests with all their limitations play a vital role in strength determination. Two such test methods normally available are the following:

(a) Rebound test method

(b) Ultrasonic method

(a) Rebound test method

Rebound test equipment and operation A Swiss engineer, Ernst Schmidt, developed a practicable rebound test hammer in the late 1940s for the first time and modern versions are based on this test. Figure 3.4 shows the basic features of a typical type of hammer which weighs less than two kg.

The spring-controlled hammer mass slides on a plunger within a tubular housing. The plunger rotates against a spring when pressed against a concrete surface and this spring is automatically released when tensioned, causing the hammer mass to impact against the concrete through the plunger. When the spring controlled mass rebounds it takes with it a rider which slides along a scale and is visible through a small window in the side of the casing. The rider can be held in position on the scale by depressing the locking button. The equipment is very simple to use. The scale reading is known as the rebound number and is an arbitrary measure as it depends on the energy and the mass used. With this number, the compressive strength of concrete can be obtained from the graph attached with the instrument.

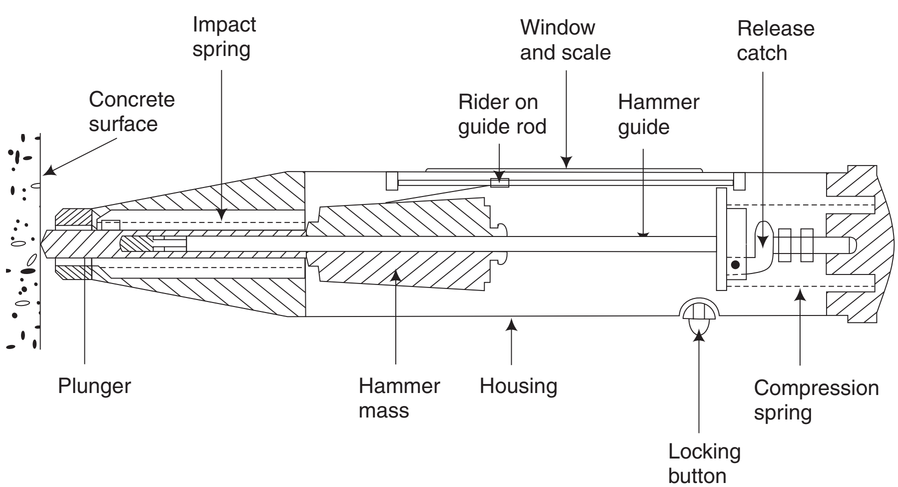


Fig. 3.4 *Typical rebound hammer*

Procedure The reading is very sensitive to local variations of the concrete, especially aggregate particles close to the surface. It is therefore necessary to take several readings at each test location and to find their average between 9 and 25 readings taken over an area not exceeding 300 mm with the impact points not less than 20 mm from each other or from the edge. The use of grid to locate these points reduce operator bias. The surface must be smooth, clean and dry and properly formed. In case rough surfaces are unavoidable they should be rubbed smooth with carborundum stone.

(b) Ultrasonic method In ultrasonic pulse velocity method, the time of travel of an ultrasonic pulse, passing through the concrete to be tested is measured. This is shown in Fig. 3.5. The pulse generator circuit consists of an electronic circuit for generating pulses and also a transducer which transforms these electronic pulses into mechanical energy having vibration frequencies in the range of 15–50 kHz. The time of travel between initial onset and the reception of the pulse is measured electronically. The path length between transducer when divided by the time of travel, gives the average velocity of wave propagation.

With the velocity of wave propagation, the quality and compressive strength of concrete can be obtained as per the classification in Table 3.4.

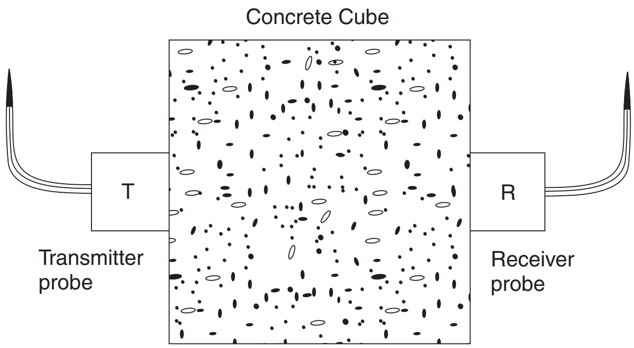


Fig. 3.5 *Direct transmission of ultrasonic waves*

Table 3.4 Quality gradings for concrete

Velocity km/s	*Classification (Quality)*	*Overall in situ compressive strength N/mm²*
4.0 and above	Very good	30 to 35
3.5 to 4.0	Good	25 to 30
3.0 to 3.5	Medium	20 to 25
3.0 and below	Poor	15 to 20

3.7 STEEL SECTIONS **[May, June 2011, 2014; Nov, Dec 2012]**

Steel is very ductile and has elastic properties. Mild steel having a carbon content of 0.1 – 0.25 per cent is used for structural work. To be used in construction works steel must be available in a certain forms. These are called market forms and are discussed as follows.

3.7.1 Bars

Bars are the common form of steel in building construction. These may have either round or square cross sections. Square sections of size 5 – 32 mm are commonly used in building works. These square bars are used as railings in buildings and for grillwork. Square bars are designated as ISSQ (an acronym for Indian Standard Square) bars.

Bars are available in lengths varying from 10 – 12 m. The common round bars vary from 6-32 mm in diameter. These round bars are used in reinforced concrete and reinforced brickwork constructions. Certain special type of bars having slight projections on its surface are also used as reinforcement. These are called as deformed bars. Their size generally varies from 8 – 32 mm.

3.7.2 Plates

Rolled plates have a maximum area of 30 m^2. The thickness of the plates varies from 5 – 28 mm. Plates thinner than 5 mm are called *sheets*. Larger plates are thicker at the centre than at the edges. These plates are used as webs and flanges for deep beams, column flanges, column bases, etc.

3.7.3 Flats

These are rolled as in the case of plates but are much longer and have shorter width. The width varies from 18–500 mm and the thickness varies from 3–80 mm. Flats are costlier than plates. These are also used in grill works and railings.

3.7.4 Angle Sections

Angle sections may be of equal legs or unequal legs as shown in Fig. 3.6. Equal angle sections are available in sizes varying from 20 mm × 20 mm × 3 mm to 200 mm × 200 mm × 25 mm. The corresponding weights per metre length are 9.0 N and 736.0 N respectively. Unequal angle sections are available from 30 mm × 20 mm × 3 mm to 200 mm × 150 mm × 18 mm. The weights per metre length are 11.0 N and 469.0 N respectively.

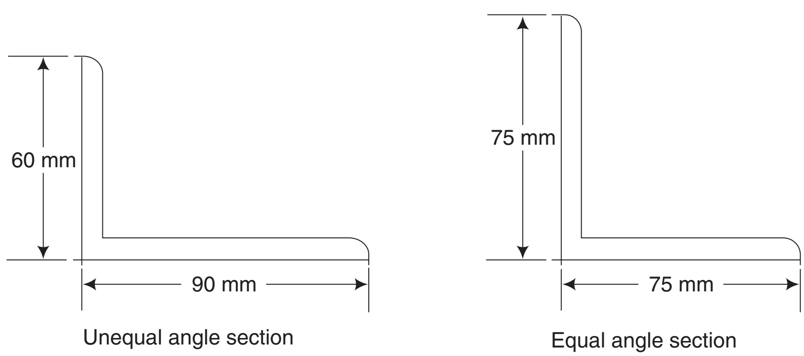


Fig. 3.6 *Angle sections*

Angle sections are used in the construction of steel roof trusses, filler joist floors, steel columns, steel beams and as stiffeners in huge girders. They are mainly used in the construction of steel bridges.

3.7.5 Channel Sections

A channel section consists of a web with two equal flanges as shown in Fig. 3.7. Typically a channel section is designated by the height of web and the width of flange. These sections are available from 100 mm × 45 mm to 400 mm × 100 mm with weight per metre length of 58.0 N and 494.0 N respectively.

Channel sections are widely used as structural members of the steel-framed structures. These are used in the construction of built-in columns, crane girders, beams and steel bridges.

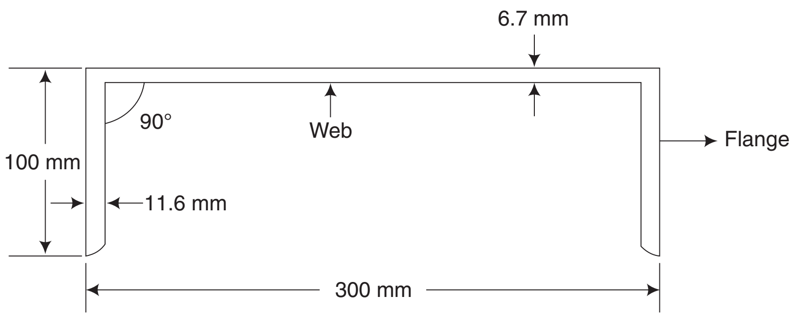


Fig. 3.7 *Channel section*

3.7.6 I-sections

These are popularly known as rolled steel joists (RS joists) or beams. An I-section consists of two flanges connected by a web as shown in Fig. 3.8 (a). It is designated by overall depth, width of flange and weight per metre length. These are available in various sizes from 75 mm × 50 mm at 61 N/m to 600 mm × 210 mm at 995 N/m. Wide flange beams are available in sizes varying from 150 mm × 100 mm at 170 N/m to 600 mm × 250 mm at 1451 N/m. Sections suitable for columns are available in H-sections which vary in sizes from 150 mm × 150 mm at 271 N/m to 450 mm × 250 mm at 925 N/m as shown in Fig. 3.9 (b).

RS joists are economical in material and are suitable for floor beams, lintels, columns, etc. The economic use of material is achieved by concentrating the material in the two flanges where bending stresses are maximum. Heavy weights with unequal I-sections are used as rails.

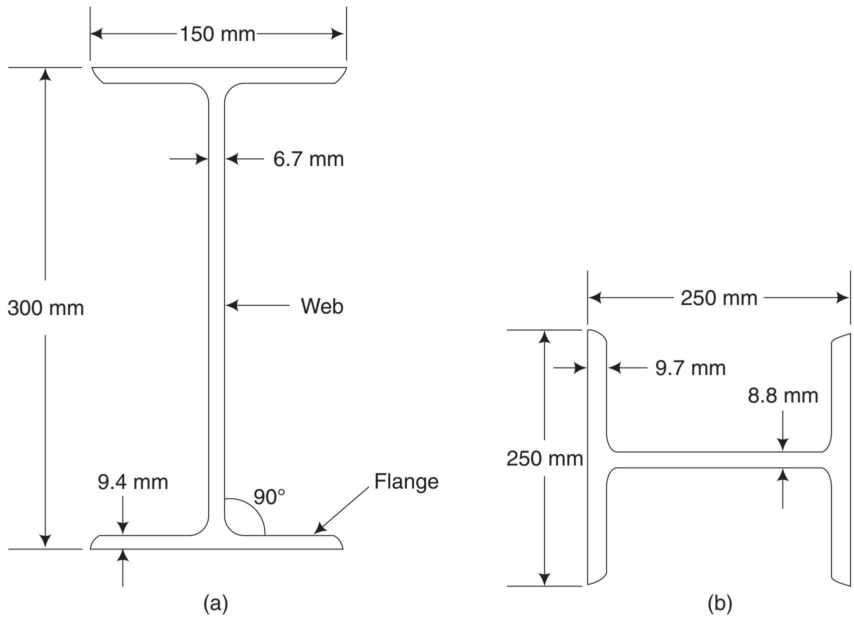


Fig. 3.8 (a) *I-section,* (b) *H-section,* (c) *T-section*

3.7.7 T -Sections

A T-section consists of a web and a flange as shown in Fig. 3.8 (c). It is designated by its overall dimensions and thickness.

The sections are available in sizes varying from 20 mm × 20 mm × 3 mm to 150 mm × 150 mm × 10 mm with corresponding weights of 9.0 N/m and 228.0 N/m respectively. Special T-sections with unequal sides, bulbs at the bottom edge of web, etc. are also available.

T-sections are widely used as members of steel roof trusses and to form built-up sections. These are also used in T-connections in steel water tanks. These sections are used in steel chimneys, steel bridges, etc.

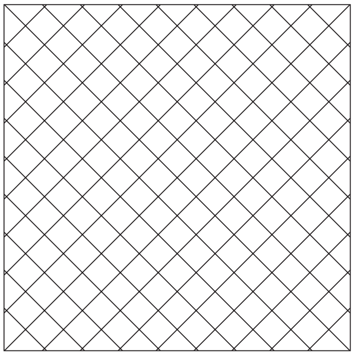
In addition to the above sections, miscellaneous sections such as acute and obtuse angle sections, trough sections and Z-sections are also available. These sections are used to a limited extent in the structural steel work.

3.7.8 Expanded Metal

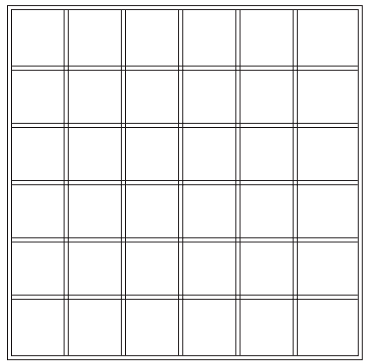
This material is formed by cutting and expanding either plain sheets or ribbed sheets of steel. The manufactured sheets are known as diamond mesh or rib mesh as shown in Fig. 3.9. Diamond mesh has sizes from 30–150 mm across the shorter length of the mesh and is obtainable from 1–3 m long and 5 m wide.

Expanded metal is used as a ferrocement reinforcement for concrete, plaster, pavement formation and as partition wall interiors.

Welded fabric which is also known as BRC fabric is a rectangular or square mesh with an aperture of about 75-300 mm. It is made of high tensile, mild steel wires in rolls or sheets as shown in Fig. 3.9.



Diamond mesh



Ribbed mesh

Fig. 3.9 *Expanded metal*

3.7.9 Steel as a Reinforcing Material

1. Reasons for steel to be considered as a good reinforcing material

(i) It develops a good bond with concrete and hence the stresses are transferred from one material to another.

(ii) It has high tensile strength.

(iii) It has high modulus of elasticity.

(iv) Its temperature coefficient of expansion and contraction is same as that of concrete and so thermal stresses do not develop.

(v) It is cheap and readily available.

2. Choice of reinforcing steel

(a) Reinforcing steel should be chosen such that it can be incorporated in the concrete to form a monolithic structure.

(b) The reinforcing steel should be of the smaller section to avoid stress concentration.

3. Forms of reinforcing steel

(a) Round bars It is a commonly adopted form of reinforcing steel.

(b) Flat bars It is more useful in tanks and pipes as they increase effective thickness.

(c) Square bars

(d) Reinforcement in the form of fabric It is used in roads, walls and floor slabs where tensile stresses develop more than in one direction. It is more convenient than placing individual bars at right angles to each other. It claims more tensile strength, better bond with concrete, checking of shrinkage and temperature cracks.

4. Types of reinforcing steel

(a) Mild steel

(b) High yield strength deformed bars or Tor steel

(a) Mild Steel

1. Stress-strain curve From the tension test on mild steel, load vs extension or stress-strain diagram is plotted as in Fig. 3.10.

(i) Elastic stage (a to c) Load is increased gradually in the region *(a* to *b)* where the stress is directly proportional to strain. That is material obeys Hookes law works up to *b* which is known as the limit of proportionality.

Beyond the limit of proportionality, material ceases to obey Hooke's law, i.e., the curve falls away from straight line *ab* produced. However, material remains elastic up to *c* which is called elastic limit though for all practical purposes *b and c* are the same.

(ii) Yield stage (d to e) Beyond the elastic limit load on the specimen increases with strain till the point *d* is reached. Beyond *d,* there is a sudden drop in load from *d* to *e. d* is known as upper yield point and *e* is denoted as lower yield point. Large deformation with no increase in load occurs in *ef* which is called plastic yielding.

(iii) Ductile stage (f to g) Beyond *f,* the material offers resistance to further straining up to the point g *and fg* is called ductile stage.

(iv) Plastic yielding stage (g to h) Specimen extends almost at constant load. From *g* to *h,* the deformation is called plastic yielding, *h* being ultimate load point where the load is the highest and corresponding stress is called ultimate stress.

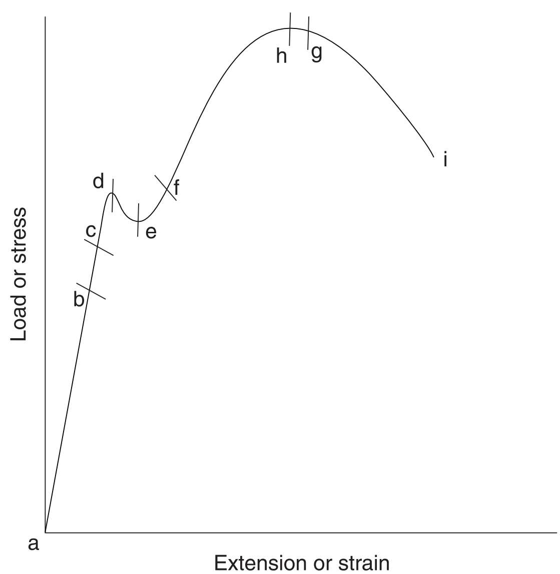


Fig. 3.10 *Stress-strain curve for mild steel*

(v) Load extension stage (hi) Final stage *hi* occurs very rapidly. In this stage specimen extends under decreasing load. At the breaking point *i,* the neck forms and it breaks down into two pieces.

2. Properties of mild steel Following are the properties of mild steel.

1. It can be magnetised permanently.
2. It can be readily forged and welded.
3. It cannot be easily hardened and tempered.
4. It has fibrous structure.
5. It is malleable and ductile.
6. It is not easily attacked by salt water.
7. It is tougher and more elastic than wrought-iron.
8. It is used for all types of structural work.
9. It rusts easily and rapidly.
10. Its melting point is about 1400°C.
11. Its specific gravity is 7.80.
12. Its ultimate compressive strength is about 80–120 kN per cm^2.
13. Its ultimate tensile and shear strengths are about 60–80 kN per cm^2.
14. Chemical composition: Sulphur 0.06%
    Phosphorous 0.065 %
    Carbon up to 0.1%

3. Usage It is observed that steel is required for the existence of the heavy and light engineering industries, ship building, railways and rolling stock, automobiles, sheet metal industries, power generation and electrical industries, etc. It should also be noted that the entire range of electrical engineering industry depends upon the property of magnetism of steel.

(b) High yield strength deformed bars or Tor steel

1. Definition To increase the resistance to slipping between steel bars and the concrete, the surface of the bars is sometimes roughened. Such bars are known as deformed bars or ribbed tor steel or HYSD bars.

2. Manufacturing It is manufactured by controlled cold twisting of hot rolled deformed bars.

3. Chemical composition Carbon—0.3%; Sulphur—0.055%; Phosphorous—0.055%.

4. Grades Tor 40 with a yield strength of 415 N/mm^2; Tor 50 with a yield strength of 500 N/mm^2.

5. Economy It is given in Table 3.5.

Table 3.5

	Mild steel	*Tor steel*	*Per cent of saving in weight*	*Total saving*
Tension	100%	60%	40%	
Compression	100%	70%	30%	33%
Shear distribution	100%	75%	25%	
Reinforcement	100%	80%	20%	

6. Properties

(i) Tor steel is weldable.

(ii) Ultimate strength is 55000 N/mm^2.

(iii) Elongation is 12 per cent.

(iv) Stress–strain curve is shown in Fig. 3.11.

7. Usage Tor steel is a safe, efficient, economical reinforcement suitable for all types of RCC constructions such as buildings, roads, bridges, reservoirs, irrigation projects, hydroelectric, thermal and nuclear power projects, docks and harbours, marine structures, pile foundations, public health engineering works, precast concrete, etc.

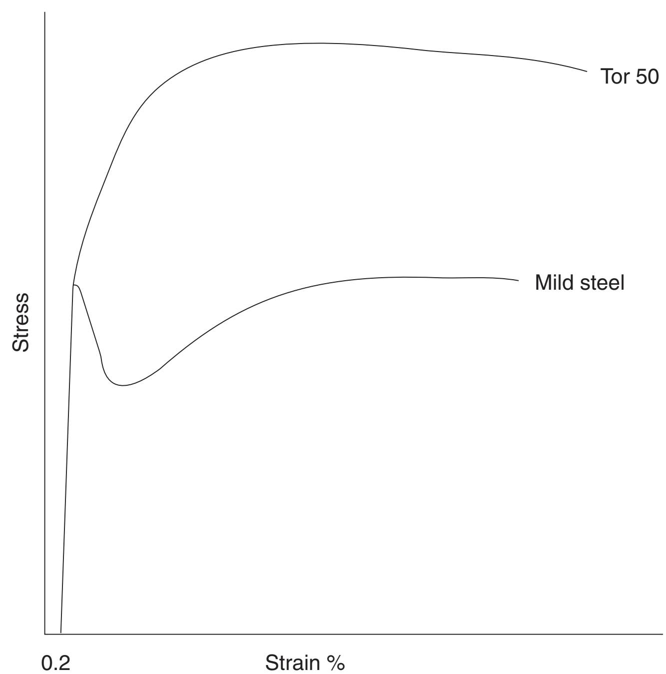


Fig. 3.11 *Stress-strain curve for Tor steel and mild steel*

8. Advantages

(i) It has 65 per cent greater yield strength.
(ii) It has 100 per cent greater bond strength.
(iii) It has highest fatigue strength.
(iv) It has high bendability.
(v) It has satisfactory and easy weldability.
(vi) It gives lesser crack width.
(vii) It provides 20 per cent more factor of safety due to hyper resistance.
(viii) It is suitable for both tension and compression reinforcement.
(ix) It does not need end hooks.
(x) Net economy is achieved in cost of reinforcing steel up to 40 per cent in tension and up to 30 per cent in compression.

3.8 WOOD

Timber is a form of wood suitable for building or engineering purposes. It is obtained from trees. All trees are divided into the following two groups based on their mode of growth.

(i) *Endogenous trees* are those which grow by the formation of layers of new wood crossing and penetrating the fibres of the wood previously formed, e.g., bamboo, palmyrah, coconut, etc.
(ii) *Exogenous trees* are those which grow outwards by the addition of rings of young wood, e.g., teak, sal, etc. The cross-section of these trees shows distinct concentric rings, called annual rings. Timbers obtained from the exogenous trees are mainly used in engineering works. Exogenous trees are again sub-divided into
  (a) *Conifers* or evergreen trees which yield soft wood, e.g., pine, deodar, etc.
  (b) *Deciduous* or broad-leaf trees which yield hard wood, e.g., teak, sal, etc.

Timbers used for engineering works are mostly derived from deciduous trees.

3.8.1 Characteristics of Soft Timber

(i) Soft timber is light in weight.
(ii) It is light in colour.
(iii) It is resinous.
(iv) It has straight fibres.
(v) It has distinct annual rings.
(vi) It is comparatively weak.
(vii) It can be split easily.

3.8.2 Characteristics of Hard Timber

(i) Hard timber is heavy in weight.
(ii) It is dark in colour.
(iii) It is non-resinous.
(iv) It is close grained.
(v) It does not show clear annual rings.
(vi) It is strong.
(viii) It is durable.

3.8.3 Structure of an Exogenous Tree

The cross-section of an exogenous tree is shown in Fig. 3.12.

Pith is the innermost, central portion of a tree. It consists of cellular tissues.

Heartwood is the inner annual rings surrounding the pith. Heartwood is darker in colour and is strong and durable. Heartwood is used for all engineering works.

Sapwood is the portion containing the outer annual rings between the cambium layer and the heartwood. It is light in colour as compared to heartwood. Sapwood cannot be used for any engineering work because it contains large amount of moisture and is liable to decay quickly.

Cambium layer is the soft ring surrounding the outermost ring of sapwood.

Bark is the outermost layer or skin of the trunk which covers the wood.

Medullary rays are the thin radial fibres extending from pith to cambium layer.

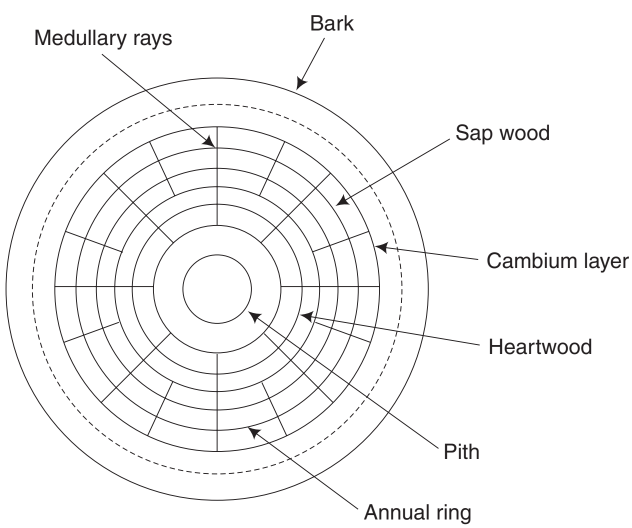


Fig. 3.12 *Cross-section of wood*

3.8.4 Seasoning of Timber

The process of reducing the moisture from timber is known as seasoning. Freshly felled tree contains large amount of moisture. If the percentage of moisture is more than 20 per cent then different types of fungus and insects attack the wood. Hence timber needs seasoning. Following methods can be used for seasoning the timber.

1. Natural Seasoning or Air Seasoning In this method, sawn pieces of timber are stacked on stone or brick supports, a little above the ground in layers with sufficient space between them under a shed. They are left this way to get free circulation of air for a long period (two to four years). This is a slow method of seasoning but it is cheap and simple.

2. Water Seasoning In this method, the logs of wood are immersed in water, preferably in the running water of stream or river for two to four weeks. By doing so, sapwood is removed. The logs are then taken out and kept in open air to dry out. Such logs neither warp nor develop cracks but become brittle and their strength is also reduced.

3. Boiling In this method, the timber is either boiled in water or exposed to the action of water for about four hours. It is then taken out and slowly dried. Even though the period of seasoning is less, it is an expensive method.

4. Electrical Seasoning In this method, high frequency alternating current is passed through the timber. The timber gets heated and dries out. This method results in uniform seasoning of wood but the capital cost of equipment needed is more. This method is used in the manufacture of plywood.

5. Chemical Seasoning In this method, green timber is soaked in saturated salt solution, then removed and seasoned in the ordinary way. The interior moisture is drawn out by the saturated salt solution and the timber part dries before the outer one.

6. Kiln Seasoning In this method, the timber is stacked in a chamber or kiln. The chamber is artificially heated to 40° to 90°C by passing hot air in it for three to 12 days. The time and temperature required for seasoning depends on the type of the timber. This is one of the best artificial methods for seasoning wood. By using this method, moisture content in wood can be lowered to a large extent in a shorter period. This method also ensures the availability of well seasoned wood throughout the year.

3.8.5 Properties of Wood

Most important properties of wood may be discussed under the following general headings.

1. Colour and Odour Most trees are characterised with a typical colour and odour. A freshly cut teakwood has a golden yellow shade. The softwoods like deodar and pine show light (white) colours. As regards to odour (smell), quite a few woods are immediately identified by their characteristic smell. Teak wood has an aromatic smell.

2. Specific Gravity Wood is a very light material, its specific gravity being always less than one (that of water). Woods show good deal of variation in their specific gravity. Some varieties may be as light as 0.3 whereas in other varieties of timber, the specific gravity may be up to 0.9. This depends on their structure and presence of pores in them.

3. Moisture Content All woods are hygroscopic in nature. They gain moisture from atmosphere. Wood may absorb moisture more than 2–2.5 times than its own weight. A moisture content of 12–15 per cent in air-seasoned woods is considered quite safe for timber being used in any construction.

4. Grain In a normal wood, the tracheids and vessels (collectively called as fibres) grow parallel to the length of the tree trunk. This type of structure is called a straight grain. The fibres may be very tightly and closely packed giving rise to a fibre grained texture in wood. In other cases, they may be broad and quite wider (comparatively). Such a structure is then termed as coarse grained. Sometimes the fibres do not grow essentially parallel to the trunk. These may grow in a twisted, spiral or interlocked manner. Such structure is called cross-grained.

5. Shrinkage and Swelling The newly cut wood loses moisture when made to dry naturally or artificially. On drying, the wood undergoes a shrinkage, Similarly, dry wood on getting rain soaked or wetted may undergo considerable swelling. Thick-walled cells shrink more than the thin walled cells. It is for this reason that the hardwoods shrink more than the softwoods.

6. Strength The most important fact about the strength of timber is that it is not the same in all the directions. The strength of wood is determined with reference to the direction of grain of the wood under load. Besides grain, many other factors also influence the strength of timber. These are

(a) Density—Higher the density of timber, greater will be its strength.

(b) Moisture content—Higher the moisture content, lower is the strength of timber.

(c) Presence of defects—There may be a number of natural and artificial defects in timber such as cross-grain, knots and shakes, etc. All of them cause a decrease in the strength of the timber.

3.8.6 Uses of Timber

(i) It is used for door and window frames, shutters of doors and windows, roofing materials, etc.
(ii) It is used for formwork of cement concrete, centering of an arch, scaffolding, etc.
(iii) It is used for making furniture, agricultural instruments, sports goods, musical instruments, etc.
(iv) It is used for making railway coach wagons.
(v) It is used for making toys, engraving work, matches, etc.
(vi) It is used for railway sleepers, packing cases, etc.
(vii) It is used for temporary bridges and boat construction.

3.8.7 Plywood

The meaning of term *ply* is a thin layer. Plywoods are boards which are prepared from thin layers of wood or veneers. Three or more veneers in odd numbers are placed one above the other such that the direction of grains of successive layers are at right angles to each other. They are held in the desired position by application of suitable adhesives. The placing of veneers normal to each other increases the longitudinal and transverse strength of plywoods.

Plywoods are used for various purposes such as ceilings, doors, furniture partitions, panelling walls, packing cases, railway coaches, formwork for concrete, etc.

Forms of Plywood Plywoods are available in different commercial forms such as batten board, lamin board, metal faced plywood, multi-ply, three-ply, veneered plywood, etc.

Batten Board It is a solid block with core sawn thin wood as shown in Fig. 3.13. The thickness of core is about 20 mm to 25 mm and the total thickness of board is about 50 mm. These boards are light and strong. They do not crack or split easily.

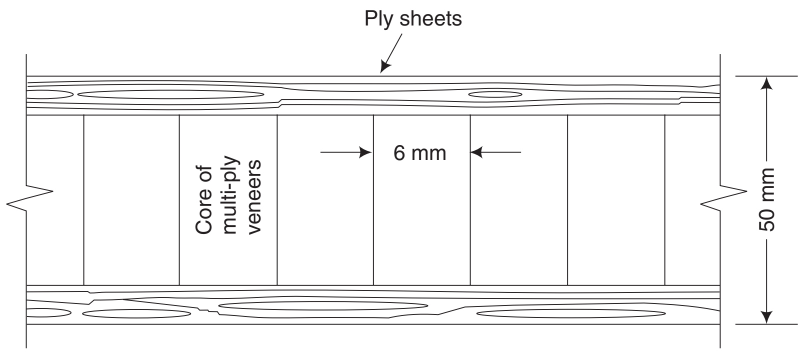


Fig. 3.13 *Batten board*

Lamin Board It is similar to batten board except that the core is made of multi-ply veneers as shown in Fig. 3.14. The thickness of each veneer does not exceed 6 mm and the total thickness of the board is about 50 mm.

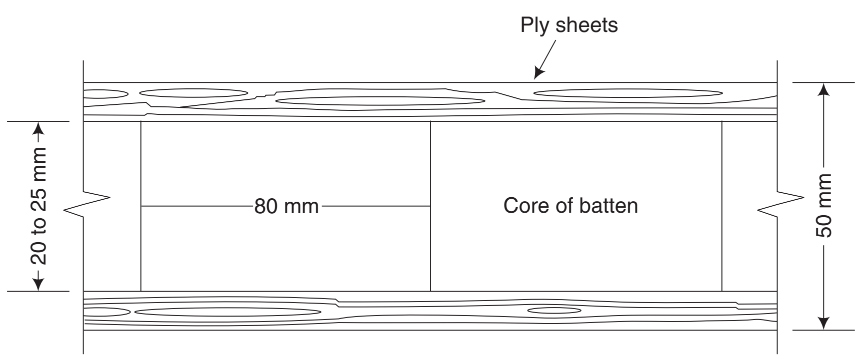


Fig. 3.14 *Lamin board*

In metal faced plywood, the core is covered by a thin sheet of aluminium, copper, bronze, steel, etc. This plywood is rigid and it is cleaned.

The plywoods made from more than three plies are designated as multi-ply. The number of veneers is odd. The thickness may vary from 6 mm to 25 mm or more.

The plywoods prepared from three plies only are known as three-ply. In veneered plywood, the facing veneer is of decorative appearance and it is used to develop an ornamental effect.

Advantages

1. Plywoods are light in weight.
2. They are available in different sizes.
3. Plywoods do not split in an axial direction.
4. They possess uniform tensile strength in all directions.
5. They are not easily affected by moisture.

3.9 PLASTICS

Plastics are organic substances which consist of resins in combination with a moulding compound. The synthetic resins may be phenol, vinyl, cellulose, etc. and the moulding compound may be fillers, plasticizers, solvents, pigments, hardeners, etc.

Advantages

1. They have high resistance to corrosion.
2. They are light in weight and hard.
3. They are not affected by fungus, vermins and rot.
4. They can be used as thermal and electrical insulations.
5. They can be easily moulded.
6. They have good shock-absorbing capacity.
7. They have pleasing appearance.
8. They are cheap.

Types of Plastics can be divided into two types.

1. Thermoplastics
2. Thermo-setting plastics

3.9.1 Thermoplastics

Plastics which become soft when heated and hard when cooled are called thermoplastics. The process of softening and hardening may be repeated for an indefinite time. It is possible to shape and reshape these plastics by means of heat and pressure. One important advantage of this variety of plastics is that the scrap obtained from old and worn out articles can be effectively used again.

The following are some of the important thermo plastics.

1. Acrylic Methylmethacrylate is an important constituent of this class of plastics. These are more transparent, rough and strong and do not shudder under impact. It is not affected by moisture and light acids. It is used in place of glass doors and windows and safety glass in automobile and aircrafts.

2. Cellulose acetate They are made from cotton seed and used as electric cables, hand rails, etc.

3. Polythene Transparent, chemically unaffected by moisture and temperature. Used for making pipes, covers for curing of cement and moisture proof packings.

4. Perpex Formed in the shape of sheets which do not break easily. Used as lamp shades, electric fittings and various other building usages.

5. Poly vinyl chloride It is a product obtained from vinyl chlorides and acetate. It resists attacks by acids and alkalis. It is light weight and withstands wear and tear. It is used as drainage pipes, floor-finish, emulsion paints, etc.

3.9.2 Thermo-setting Plastics

The thermo-setting plastics are the plastics which become rigid when moulded at suitable pressure and temperature. This type of plastic passes originally through thermo plastic stage. Thermo-setting plastics are strong, durable and hard. They are mainly used in engineering applications of plastics.

The commonly used thermo-setting plastics are phenol formaldehyde, phenol-furfuraldehide and urea-formaldehyde plastics.

Phenol formaldehyde It is formed by heating phenol and benzene in the presence of suitable catalysts.

Phenol-furfuraldehyde It is formed by digesting husks of rice, oat, ground-nut with H_2S0_4 distilling the mixture to separate the furaldehyde vapour and allowing the vapours to react with phenol in presence of catalysts.

Urea-formaldehyde Urea reacts with formaldehyde in presence of catalysts. These are used for making dishes, drinking glasses, plates, etc.

Uses

1. They are used for making plumbing fixtures, fittings and water storage tanks.
2. They are used for making floor and wall tiles.
3. They are used to produce pipes.
4. They are used to form flat sheets used for enclosure panels.
5. Foamed plastics are used for roofing.
6. They are used for doors and windows frames.
7. Plastics are used as an insulating material.

3.10 PROPERTIES OF BUILDING MATERIALS

3.10.1 Introduction

Building materials are found to be the basic elements for all engineering structures. So the behaviour of the structure depends on the behaviour of the basic elements, i.e. on the various characteristics and properties of the building material. Such properties may be classified into various categories as follows.

1. Physical properties
2. Mechanical properties
3. Chemical properties
4. Electrical properties
5. Magnetic properties
6. Optical properties
7. Thermal properties

From constructional aspects, the physical and mechanical properties are predominant. Hence it is essential for a civil engineer to have knowledge on the various physical and mechanical properties of building materials.

3.10.2 Physical Properties

Various physical properties of a building material are as follows.

(i) Bulk density
(ii) Chemical resistance
(iii) Coefficient of softening
(iv) Density
(v) Density index
(vi) Durability
(vii) Porosity
(viii) Specific heat
(ix) Thermal conductivity
(x) Thermal capacity
(xi) Water absorption
(xii) Permeability

(i) Bulk Density It is defined as the mass per unit volume of material in its natural state, i.e., including volume of pores and voids. Table 3.6 lists bulk densities of different building materials.

(ii) Chemical Resistance The ability of the material to resist against the action of acids, alkalies, gases and salt solution is known as its chemical resistance. Chemical resistance is carefully examined while selecting material for sewer pipes, hydraulic engineering installations, sanitary facilities, etc.

Table 3.6 Bulk densities of common building materials

S.No.	*Building materials*	*Bulk density in kN/m³*
1.	Clay brick	16 to 18
2.	Dense limestone	18 to 24
3.	Granite	25 to 27
4.	Gravel	14 to 17
5.	Heavy concrete	18 to 25
6.	Light concrete	5 to 18
7.	Sand	14.5 to 16.5
8.	Steel	78.5

(iii) Coefficient of Softening It is the ratio of compressive strength of material saturated with water to that in dry state. Materials having coefficient of softening more than or equal to 0.8 are referred to as the water-resisting materials.

(iv) Density It is defined as the mass per unit volume of the material in its homogeneous state, i.e. neglecting the volume of pores and voids.

(v) Density Index The ratio of bulk density of the material to its density is known as its density index. Thus, it denotes the degree to which its volume is filled up with solid matter. Density index for most of the building materials is less than unity.

(vi) Durability The property of a material to resist the combined action of atmospheric and other factors is known as its durability. The life and maintenance cost of any structure depends upon the durability of the materials which it is composed of.

(vii) Porosity The degree by which the volume of material is occupied by pores is termed as porosity. It is the ratio of volume of voids to the total volume of the specimen.

(viii) Specific Heat The term specific heat indicates the quantity of heat (expressed in kilocalories) required to heat one N of material by one degree centigrade.

(ix) Thermal Conductivity Thermal conductivity of a material is defined as the amount of heat in kilocalories, that will flow through a unit area of the material with unit thickness in unit time and when the difference of temperature on its faces is also unity. The reciprocal of thermal conductivity of a material is termed as its thermal resistivity.

(x) Thermal Capacity The property by which the material absorbs heat is termed as its thermal capacity. It is obtained by the following equation

$$T = H/(M \times (t_1 \sim t_2))$$

where

T = thermal capacity in J/N °C

H = quantity of heat required to increase the temperature of a material from t_1 to t_2 in J

M = mass of material in N

$t_1 \sim t_2$ = temperature difference of material before and after heating in °C *(xi) Water Absorption* The ability of a material to absorb and retain water is termed as its water absorption. It is expressed either as percentage of weight or percentage of volume of dry material. It mainly depends on the bulk density and porosity of the material.

(xii) Permeability The capacity of a material to allow water to pass through it under pressure is referred as its permeability. It denotes the quantity of water that will pass through an unit cross-sectional area of the material in one hour at constant pressure.

3.10.3 Mechanical Properties

The various mechanical properties of building material are as follows.

(i) Abrasion
(ii) Elasticity
(iii) Plasticity
(iv) Strength
(v) Impact strength
(vi) Wear
(vii) Fatigue
(viii) Hardness
(ix) Brittleness
(x) Ductility
(xi) Malleability
(xii) Toughness

(i) Abrasion It is the property of a material by which it resists the action of moving load. It is found by dividing the difference in weights of the specimen, before and after abrasion with the area of abrasion.

(ii) Elasticity The property by which a material regains its original shape and position after the removal of external load is known as elasticity.

(iii) Plasticity It is the property of a material, by which no deformation vanishes, when it is relieved from the external load.

(iv) Strength The ability of a material to resist failure under the action of external load is known as its strength. The loads to which a material is commonly subjected to are compression, tension and bending. The corresponding strength is obtained by dividing the ultimate load with the cross-sectional area of the specimen.

(v) Impact strength It is defined as the quantity of work required to cause failure per unit of its volume. Thus, the impact strength indicates the toughness of the material.

(vi) Wear The failure of a material under the combined actions of abrasion and impact is known as its wear. It is usually expressed as a percentage of loss in weight and it is very important to decide the suitability of a material for use of road surfaces, railway ballast, etc.

(vii) Fatigue When the materials are subjected to repetitive fluctuating stress, they will fail at a stress much lower than that required to cause fracture under steady loads. This property is known as fatigue.

(viii) Hardness It is the ability of a material to resist penetration by a harder body. It plays an important role in deciding the workability and use of a material for floors and road surfaces. For stone materials, hardness can be determined with the help of Mohr's scale of hardness. It is a list of ten materials arranged in the order of increasing hardness as shown in Table 3.7. The level of hardness of a material lies between the hardnesses of two materials, i.e. the one which scratches and the other which is scratched by the material to be tested.

(ix) Brittleness A material is said to be brittle when it cannot be drawn into a wire by tension. A brittle material fails suddenly under pressure without appreciable deformation preceding the failure. Concrete, glass, cast-iron, rock materials, etc. are some of the examples of brittle materials.

(x) Ductility It is a property of a material by which it can be drawn into a wire by tension.

(xi) Malleability The property by which a material can be uniformly extended in a direction without rupture is known as malleability. This property finds its applications in many operations such as forging, hot rolling, etc.

(xii) Toughness Toughness is the property of a material that enables it to absorb energy without fracture. This property is useful in shock loading.

Table 3.7

S.No.	Material	Remarks
1.	Talcum	Readily scratched by finger nail
2.	Rock-salt or gypsum	Scratched by finger nail
3.	Calcite	Readily scratched by a steel knife
4.	Fluorite	Scratched by a slightly pressed steel knife
5.	Apatite	Scratched by a heavily pressed steel knife
6.	Feldspar	Slightly scratches glass and is not scratched by a steel knife
7.	Quartz	Readily scratches glass and is not scratched by steel knife
8.	Topaz	Readily scratches glass and is not scratched by steel knife
9.	Corundum	Readily scratches glass and is not scratched by steel knife
10.	Diamond	Readily scratches glass and is not scratched by steel knife

Short-Answer Questions

1. Give examples for igneous, sedimentary and metamorphic rocks.
2. How are igneous rocks formed?

3. What are the major operations involved in the manufacture of bricks?
4. What are the dimensions of a standard brick?
5. What are the raw materials used in manufacture of cement?
6. Why gypsum is added during the manufacture of cement?
7. What is meant by hydration of cement?
8. What is the need for reinforcement in RCC?
9. Draw stress–strain diagram for mild steel.
10. What is meant by M15 concrete?
11. How are bricks classified?
12. How are rocks classified based on its formation?
13. What do you mean by reinforced concrete? What is the necessity of reinforcing the concrete?
14. What is expanded metal and where it is used?
15. What are the uses of channel and T-sections?
16. What are the main functions of a civil engineer?
17. What are the objectives of surveying?
18. What are the constituents of a brick.
19. List various types of cement.
20. What are the advantages of reinforced cement concrete?
21. What are the types of light weight concrete and polymer concrete?
22. What is the main disadvantage of normal concrete?
23. What are the several ways in which aerated concrete is manufactured?
24. What do you mean by no-fine concrete?
25. What is high density concrete and where is it mainly used?
26. List the monomers normally used in polymer concrete.
27. What are the applications of PIC?
28. What is meant by FRC?
29. What are the functions of fibres in FRC? State the different types of fibres.
30. Define workability.
31. Define compressive strength of concrete.
32. What are the functions of admixtures?
33. What do you understand by non destructive testing of concrete?
34. List out the test methods normally available for non-destructive testing of concrete.
35. What is the main advantage of using tor steel?
36. Draw the stress–strain curve for tor steel.

37. Write down the chemical composition of tor steel. What are the grades of tor steel?
38. What are endogenous and exogenous trees?
39. Draw the cross-section of an exogenous tree.
40. Define the following terms.
    (i) Pith
    (ii) Cambium
    (iii) Bark
    (iv) Medullary rays
    (v) Heartwood
    (vi) Sapwood
41. What is seasoning of timber?
42. What are the uses of timber?
43. What are plywoods?
44. Define plastics. What are the different types of plastics?
45. Give examples for thermo plastics and thermo-setting plastics.
46. Define hardness.
47. Define fatigue and ductility.
48. Define porosity.
49. Define water absorption.
50. Define thermal conductivity.
51. Define mortar
52. What is gauged mortar?
53. What is the type of mortar used for plastering and pointing works?
54. Why steel is considered as a good reinforcing material?
55. What are the various forms of reinforcing steel?

Exercises

1. List the uses of the following construction materials: bricks, stones, cement, cement concrete and steel.
2. What are the qualities of a good brick?
3. What are the requirements for a stone which is to be used as a building material?
4. Explain the properties of cement.
5. Which are the normal steel sections available in the market? Give neat sketches.
6. Explain in detail, the functions of a civil engineer.
7. Explain the constituents of brick.
8. Describe the various types of cement, specifying the applications for each.

9. Briefly explain the different types of light weight concrete and list out its advantages.
10. Write short notes on the following types of concrete.
    (i) High-density concrete
    (ii) Polymer concrete
    (iii) Fibre reinforced concrete
11. Describe briefly the factors affecting workability.
12. Explain, how you will measure the workability of the concrete mixture.
13. Briefly explain about the testing of hardened concrete.
14. Explain the various factors affecting the compressive strength of concrete.
15. Explain the methods of testing the tensile strength of concrete with a neat sketch.