Govt. Polytechnic Mandkola, Palwal
Name of the faculty: - Manoj Raghav (Lecturer in Civil Engg. Deptt.)
E-Content Subject: - Concrete Technology
Semester: - 3rd

DETAILED CONTENTS

UNIT I

1. Introduction to Concrete

1.1 Definition of concrete, properties of concrete. Advantages and disadvantages of concrete.

2. Ingredients of Concrete

2.1 Cement: Introduction only

2.2 Aggregates:

2.2.1 Classification of aggregates according to size and shape

2.2.2 Characteristics of aggregates: Particle size and shape, surface texture, specific gravity of aggregate; bulk density, water absorption, surface moisture, bulking of sand, deleterious materials soundness

2.2.3 Grading of aggregates: coarse aggregate, fine aggregate; All-in- aggregate; fineness modulus; interpretation of grading charts

2.3 Water: Water Quality requirements as per IS:456-2000

UNIT II

3. Water Cement Ratio

3.1 Hydration of cement principle of water-cement ratio, Duff Abram's Water-cement ratio law: Limitations of water-cement ratio law and its effects on strength of concrete

4. Properties of Concrete

4.1 Properties in plastic state: Workability, Segregation, Bleeding and Harshness

4.1.1 Factors affecting workability, Measurement of workability: slump test, compacting factor; Recommended slumps for placement in various conditions

4.2 Properties in hardened state: Strength, Durability, Impermeability, Dimensional changes.

4.3 Concrete mix design (Introduction only)

4.4 Introduction to Admixtures (chemicals and minerals) for improving performance of concrete

UNIT III

5. Concreting Operations

5.1 Storing of Cement:

5.1.1 Storing of cement in a warehouse

5.1.2 Storing of cement at site

5.1.3 Effect of storage on strength of cement

5.1.4 Determination of warehouse capacity for storage of Cement

**5.2 Storing of Aggregate: Storing of aggregate at site

**5.3 Batching (to be shown during site visit

5.3.1 Batching of Cement

5.3.2 Batching of aggregate by:

 Volume, using gauge box (farma) selection of proper gauge box

 Weight spring balances and batching machines

5.3.3 Measurement of water

**5.4 Mixing:

5.4.1 Hand mixing

5.4.2 Machine mixing - types of mixers, capacities of mixers, choosing appropriate size of mixers, operation of mixers.

5.4.3 Maintenance and care of mixers

UNIT IV

****6.1 Transportation of concrete**: Transportation of concrete using: wheel barrows, transit mixers, chutes, belt conveyors, pumps, tower crane and hoists etc.

**6.2 Placement of concrete: Checking of form work, shuttering and precautions to be taken during placement

6.3 Compaction:

6.3.1 Hand compaction

6.3.2 Machine compaction - types of vibrators, internal screed vibrators and form vibrators

6.3.3 Selection of suitable vibrators for different situations

6.4 Finishing concrete slabs - screeding, floating and trowelling

6.5 Curing:

6.5.1 Objective of curing, methods of curing like ponding, membrane curing, steam curing, chemical curing

6.5.2 Duration for curing and removal of form work

6.6 Jointing: Location of construction joints, treatment of construction joints, expansion joints in buildings - their importance and location

6.7 Defects in concrete: Identification of defects and methods of removing defects.

UNIT V

7. Special Concretes (only features)

7.1 Concreting under special conditions, difficulties, and precautions before, during and after concreting

7.1.1 Cold weather concreting

7.1.2 Under water concreting

7.1.3 Hot weather concreting

7.2 Ready mix concrete

7.3 Fly ash concrete

8. Importance and methods of non-destructive tests (introduction only)

8.1. Rebound Hammer Test

8.2. Pulse Velocity method

1. Cement

a) Introduction

- Portland cement is defined as ***hydraulic cement***, i.e., a cement that hardens by reacting with water and forms a water-resistant product.
- It is obtained by burning together, in a definite proportion, of naturally occurring ***Argillaceous*** (containing clay) and ***Calcareous*** (containing lime) materials, to a partial fusion at high temperature (about 1450°C).
- The product obtained on burning, called ***Clinker*** or ***nodules*** (5-25 mm diameter),
- Clinker is cooled and ground to the required fineness to produce ***cement***.
- Its inventor, ***Joseph Aspdin***, called it Portland cement because when hardened, it produced a material resembling stone from the quarries near Portland in England.
- During the grinding of clinker, Gypsum or Plaster of Paris is added *to adjust the setting time*. The amount of gypsum is about **3%** by weight of clinker. It also improves the ***soundness*** of cement.
- The common calcareous materials are limestone, chalk, oyster shells and marl.
- The argillaceous materials are clay, shale, slate and selected blast-furnace slag.

b) Oxide composition of Ordinary Portland cement

Lime Cao	Controls **strength** and **soundness**. Its deficiency reduces strength and setting time.	60-65
Silica SiO_2	Gives **strength**. Excess of it causes slow setting.	17-25
Alumina Al_2O_*	Responsible for **quick setting**, if in excess, it lowers the strength	3-8
Iron oxide Fe_2O_*	Gives **colour** and helps in fusion of different ingredients, hardness	0.5-6
Magnesia MgO	Imparts colour and hardness. If in excess, it causes cracks in mortar and concrete and **unsoundness**.	0.5-4
Sulphur trioxide SO_*	Makes cement unsound (volume increases)	1-2
Alkali– soda, potash ($Na_2O + K_2O$)	These are residues, and if in excess causes efflorescence and cracking. Cause *alkali aggregate reaction*.	1

- **Gypsum** $CaSO_3 \cdot 2H_2O$
  - It is added to ***retard the setting process***, by making a protective layer of Calcium Lingo Sulphate, Calcium Sulpho Aluminate around cement particles.
  - Gypsum and Plaster of paris in small percentage tend to increase the strength slightly.

c) Bogue's compounds

- The composition of Portland cement is rather complicated but it consists of the following 4 main compounds:

Tri-Calcium Silicate *Alite* **C_3S** ($3CaO \cdot SiO_2$)	30-50% Responsible for ***early strength*** as it hydrates within a week. It enables clinkers easy to grind. ***More heat of hydration*** than C_2S (500 J/gm) Increases resistance to ***freezing and thawing***, NOT used in mass concreting.
Di-Calcium Silicate *Belite* **C_2S** ($2CaO \cdot SiO2$)	20-45% It gives ***progressive strength***; Hydration goes on for a year or more. Low heat of hydration (260 J/gm) Imparts ***resistance to chemical attacks***
Tricalcium Aluminate *Celite* **C_3A** ($3CaO \cdot Al_2O_*$)	8-12% The reaction of water with C_*A is ***very fast*** and in that process ***falsh setting*** can occur. (*stiffening without strength development*) because the C-A-H prevents the hydration of C_*S and C_2S. Their hydrates do NOT contribute anything to the ***strength*** *of the concrete.*

	Their presence is ***harmful to the durability*** of concrete, particularly where the concrete is likely to be attacked by ***sulphates***. Generates maximum heat of hydration (865 J/gm)
Tetra-calcium alumino ferrite *Felite* **C_4AF** $(4CaO \cdot Al_2O_{*} \cdot Fe_2O_{*})$	6-10% Its hydrated product also does NOT contribute anything to the ***strength***. Its hydrate show a comparatively higher resistance to the attack of sulphates than the hydrates of $C_{*}A$. Hydrates within 24 hrs, Heat of hydration 420 J/gm.

d) **Sulphate attack**:

- Calcium Hydroxide, although makes cement *alkaline* (makes it corrosion resistant) reacts with sulphates present in water or soil to form Calcium Sulphates which react further with C_3A to form ***Ettringite*** (expansive hydrates) degrading the concrete.
- In case of OPC heat of hydration is approximately
  - ♦ 80 to 90 cal/gm after 28 days, and
  - ♦ 100 cal/gm after 90 days

e) Hydration of cement

- The chemical reaction between cement and water is known as hydration of cement. The reaction takes place between the active components of cement and water.
- When the cement comes in contact with water, the hydration products start depositing on the outer periphery of the nucleus of hydrated cement. This reaction proceeds slowly for **2-5 hrs**. and is called ***induction or dormant period***. The deposit of hydration products makes diffusion of water difficult, reducing rate of hydration with time.
- At any stage of hydration, the cement paste consists of gel, unreacted cement, calcium hydroxide, water and some minor compounds. The crystal of various resulting compounds gradually fills the space originally occupied by water, resulting in the stiffening of the mass and subsequent development of strength.

$$C_{*}S + H_2O \longrightarrow CSH + Ca(OH)_2$$
$$C_2S + H_2O \longrightarrow CSH + Ca(OH)_2$$
$$C_{*}A + H_2O \longrightarrow C_{*}AH_D$$
$$C_{*}A + H_2O + CaSO_3 \longrightarrow CA\ C\bar{S}H_{F2}$$ Sulphate attack

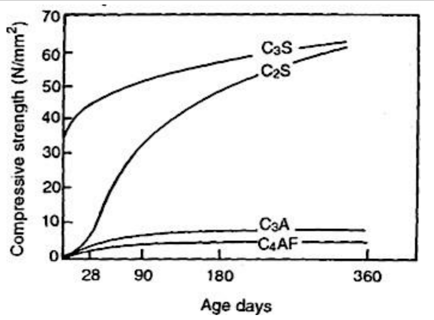
$$C_3AF + H_2O \longrightarrow C_{*}AH_D + CFH$$

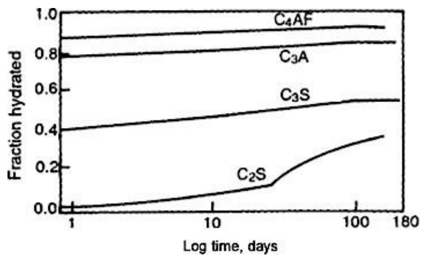
- The product CSH gel, Calcium Silicate Hydrate also known as ***tobermorite gel***, is responsible for binding action. It makes up 50-60% of the volume of solids in a completely hydrated cement paste.
- $Ca(OH)_2$ liberated during the silicate phase crystallizes in the available free space. The calcium hydroxide crystals also known as ***portlandite*** consists of 20–25% of solids. Their strength contributing potential is limited. It increases the pH of the concrete and *helps against corrosion of reinforcements*.
- The hydration of $C_{*}S$ produces lesser CSH and more $Ca(OH)_2$ as compared to hydration of C_2S. since Calcium Hydroxide is soluble in water and leaches out making the concrete porous, particularly in hydraulic structures, a cement with small percentage of $C_{*}S$ and more C_2S is recommended for use.
- It also results in higher Sulphate attack. The calcium hydroxide is utilized by pozzolanic material to make CSH gel.

f) Rate of hydration

- The reaction of compound $C_{*}A$ with water is very fast and is responsible for ***flash setting*** of cement (*stiffening without strength development*) and thus it will prevent the hydration of $C_{*}S$ and C_2S.
- Calcium Sulphate (gypsum) present in the clinker dissolves immediately in water and forms insoluble *Calcium Sulpho-Aluminate*. It deposits on the surface of $C_{*}A$ forming a colloidal membrane and consequently retards its hydration.
- The rate of heat evolution of the compounds if equal amount of each is considered will be in the following descending order:

$$C_*A > C_*S > C_3AF > C_2S$$





g) Water requirement

- About 23% of water by weight of cement is required for complete hydration of Portland cement. This water combines chemically with cement compounds and is known as *bound water*.
- About 15% by weight of cement, is required to fill the cement gel pores and is known as *gel water*. Therefore, a total of **38% water** by weight of cement is required to complete the chemical reaction.

h) Manufacturing of cement

- Dry process
  - ♦ The dry process is adopted when the raw materials are quite hard. The process is slow and the product is costly. Lime stone and clay are ground to fine powder separately and are mixed. Water is added to make a thick paste.
- Wet process
  - ♦ The operations in the wet process of cement manufacturing are mixing, burning and grinding. The crushed raw materials are fed into ball mill and a little water us added.
  - ♦ The slurry is passed to silos, where the proportioning of the compounds is adjusted to ensure desired chemical composition.

i) **Lab Testing** (§ IS 4031- physical tests)

Fineness test	➢ The degree of fineness of cement is the measure of the mean size of the grains in it. It can be measured using sieve method and **Blains air permeability** method. ➢ The fineness of cement is represented by specific surface area in cm^2 per gram. For OPC (2250 cm^2/gm) For RHC (3250 cm^2/gm) For PPC (3000 cm^2/gm)
Consistency (**P**) test	➢ This test is to estimate the quantity of mixing water to form a paste of **normal consistency** defined as the percentage water requirement of cement paste, the viscosity of which will be such that the Vicat's plunger (ϕ10mm) penetrates up to a point 5 to 7 mm from the bottom of the **Vicat's mould**. ➢ Time of gauging should not be less than 4min.
Initial and final setting time	➢ The cement paste prepared with **0.85 P** and tested in Vicat's apparatus. ➢ IST should not be less than 30 minutes. ➢ FST: paste completely loses plasticity (5mm annular collar is not able to make any impression over the surface of paste). FST should not be more than 10 hrs.
Soundness test	➢ It is done to ensure that the cement concrete does not undergo large change in volume after setting. Free lime and magnesia slake slowly causing change in volume. ➢ The chief tests for soundness are the **Le Chatelier and Autocalve** tests. ➢ **0.78P** water paste is made, and filled in a mould of diameter 50mm and height 50mm, with indicator arm of 165mm, top and bottom is covered with glass and apparatus is immersed in water at 27˚-32˚C for 24 hr. After then it is taken out and spacing is measured. The whole apparatus is then put in boiling water for 3–4 hrs. and after slowly cooling down reading is taken. For OPC (33, 43, 53 grade) the expansion should not be more than 10mm.

	➢ When **magnesia** is present Autoclave test is done, test sample of 25 × 25 × 250 mm is prepared and moist cured for 24hrs. The sample is put in an autoclave such that all the four sides are exposed to steam. A gauge pressure of 2.1N/mm^2 is maintained for 3hrs. slowly pressure and temperature of the specimen is brought to room condition and percentage change in length is calculated. ➢ For OPC the maximum percentage change in length is 0.8%.
Specific gravity test	➢ Le-chaterlier flask is used. ➢ Naphthalene or kerosene is used for measurement of volume of cement particles.
Compression test cement mortar	➢ Mortar is prepared using ***standard sand***, in ratio 1:3 (*ennor* sand). This mortar is filled inside the molds of size *7.06*cm (50cm^2 face area) in at least two layers with proper compaction. ➢ Mix the cement and sand in dry condition with a trowel for 1 min and then add water. ➢ Water L$\frac{P}{4}$ + **3**N % of combined weight (cement + sand) is added and mixed until uniform colour is achieved, time should not be less than 3 min and not more than 4 min. ➢ Mortar is placed inside the cube with proper vibration, and the properly cured at 27ºC and 90% humidity for 24 hrs, then placed in clean water. ➢ Cubes are taken out before testing and water is wiped out. Test is conducted on 3 cubes and average value is reported.
Tensile test	➢ Similar mortar as compressive strength test. L$\frac{P}{Q}$ + 2.5N % ➢ Mortar is filled inside briquettes. ➢ At least 12 specimens are prepared for testing, due to more uncertainty.
Heat of hydration	➢ In mass concreting heat released during hydration can cause shrinkage cracking. ➢ Apparatus used is Calorimeter, ➢ 60g of cement and 24 ml of distilled water are mixed for 4min at temperature 15º-25ºC. three specimen glass vials are filled with this mixture, corked and sealed with wax. ➢ The heat of hydration is obtained by subtracting the respective heat of solution of unhydrated cement calculated nearest to 0.1 calorie.

j) Types of cement

Rapid Hardening Portland cement	➢ It has high lime content & can be obtained by (C$_*S$ t, fineness t) ➢ The basis of application of RHC is hardening properties and heat emission rather than setting rate. (so little more gypsum is added to control the setting rate.) ➢ 7-day strength can be obtained in 3 days and 3-day strength in 1 day. ➢ It is subjected to large shrinkage and water requirement for workability is more. ➢ Used in speedy construction. It has better resistance to chemical attack than OPC. ➢ Concrete made with RHC can be safely exposed to frost, since it matures quickly. ➢ Ex: pavement, repair work, cold weather, precast construction ➢ (IST 30min, FST 10hrs) costs 10% more than OPC
Extra rapid Hardening cement	➢ Also called Calcium chloride cement, is made by adding 2% calcium chloride. Since it is deliquescent, it is stored under dry conditions and should be consumed within a month of its dispatch from the factory. ➢ It generates 25% more strength in initial few days. IST lower to around 20 min. Ultimate strength is same. ➢ Suitable for cold weather.
Quick setting Cement	➢ (IST 5min, FST 30min)

	➢ The quantity of gypsum is reduced and small percentage of aluminium sulphate is added. It is ground much finer than OPC. ➢ Used in under water construction, grouting to stop seepage.
Low heat cement	➢ (C_2S t, C_*S ↓, C_*A ↓) ➢ Has better resistance against the action of chemicals and salts because of less cracks. ➢ Preferred in mass concreting, dam, bridges, water tanks
Sulphate resisting cement	➢ (C_*A ↓< 5%, C_3AF ↓) ➢ Better resistance against external Sulphate attacks ➢ Underground construction, foundation and piles, sewage and water treatment plant, marine, sewer line, marshy area, canal lining.
Portland pozzolana cement	➢ It is a blended cement which is produced by either mixing first, OPC+ gypsum + pozzolanic material, or grinding and them mixing in appropriate proportions. ➢ It is ground finer than OPC, and has low heat of hydration and is economical to OPC. ➢ Rate of gain of strength is slow, but has better resistance to chemical attack has low porosity. ➢ Used in construction of hydraulic structures, marine structures, for mass concrete and sewage disposal work.
Portland slag cement	➢ (blast furnace cement slag, GGBS) ➢ Preferred in places where high durability is needed. ➢ It is more resistant to Sulphate attack and is *specified for marine work* or pipe carrying chemical and sewage.
Super sulphated cement	➢ This cement is obtained by inter-grinding 80-85% GGBS along with 10-15% hard burnt gypsum and 5% OPC clinkers. ➢ It is ground finer than OPC. ➢ It has high resistance to Sulphate attack, and low heat of hydration. ➢ It is more susceptible to deterioration under storage. ➢ Should not be used with any chemical admixtures. ➢ It is suitable for use in marine work, foundation in chemically aggressive soil, and RCC pipe buried in sulphate bearing soil.
High alumina cement	➢ Obtained by mixing of *Bauxite clinkers* and limestone, (40%–40%) ➢ The resultant product is ground finer, the main cement ingredient is monocalcium aluminate CA which interacts with water. ➢ It gains early strength, ***good chemical resistance***, and suitable in cold weather construction. ➢ It should not be used in places where temperature exceeds 18ºC. (loses strength at high temperature)
Water repellant cement (*hydrophobic*)	➢ It is manufactured by adding small amount of *stearic acid, boric acid or oleic acid* with ordinary Portland cement during grinding of clinkers. ➢ The water repellent film formed around each grain of cement reduces the rate of deterioration of the cement during long storage, transport or under unfavourable conditions. ➢ This film will be broken out at the time of mixing the cement with aggregate allowing cement particles for normal hydration. ➢ However, these water repellent materials allow a certain amount of air in the concrete, thereby increasing the workability of concrete. ➢ This type of cement is used in places of longer storage periods and extremely wet climatic conditions. this type of cement is used in water predominant construction

	sites such as dams, spillways, underwater constructions etc. however the cost of this cement is normally higher than ordinary Portland cement.
Water Proof cement	➢ It is manufactured by adding stearates of Ca, Al and Gypsum, treated with tannic acid at the time of grinding. ➢ It is resistant to penetration of water. ➢ It is used in water retaining structures like tanks, reservoir, retaining wall, swimming pool, bridge piers.

2. Aggregates

a) Fineness Modulus: It is a numerical index of fineness, giving some idea about the mean size of the particles in the aggregates.

- The fineness modulus varies between 2.0 to 3.5 for fine aggregate,
- Between 5.5 and 8.0 for coarse aggregate and
- from 3.5 to 6.5 for all-in aggregates.
- Aggregate, whose F.M. is required, is placed on a standard set of sieves (80, 63, 40, 20, 12.5, 10, 4.75, 2.36, 1.18 mm and 600, 300, 150 μm) and the set is vibrated.
- The material retained on each sieve after sieving represent the fraction of aggregate coarser than the sieve in question but finer than the sieve above.
- The sum of the cumulative percentages retained on the sieves divided by 100 gives the F.M.
- A fineness modulus of 3.0 can be interpreted to mean that the third sieve i.e., 600 μm is the average size.
- The object of finding F.M. is *to grade the given aggregate for the required strength and workability of concrete mix with minimum cement*.
- Higher F.M. aggregate result in harsh concrete mixes and lower F.M. result in uneconomical concrete mixes.

b) **Alkali- aggregate reaction** or sometimes *concrete cancer*:

- It is a phenomenon accompanied by extensive expansion and may lead in bad cases to complete disruption and disintegration of the concrete.
- The trouble is due to reaction between silica in aggregate and alkalis in the cement.
- In some cases, alkalis, mainly from the cement supplemented by alkalis in the aggregate, react with carbonates in the aggregate to produce similar result.

c) Functions of Sand:

- The functions of sand are to achieve economy by its use as adulterant in mortar, prevent shrinkage and development of cracks in mortar, furnish strength to mortar against crushing and allow carbon dioxide from the atmosphere to penetrate the fat lime mortars necessary for its air hardening.
- The *grading of fine aggregate* has a great influence on workability of mortar.
- Based on particle size distribution fine aggregate have been divided in four grades from grading zone I to IV (IS: 383). The sand becomes progressively finer in higher grades.
- The grading has great influence on workability of mortar.
  - ♦ Very fine sand results in a poor mortar and is uneconomical,
  - ♦ whereas very coarse sand produces a harsh mix affecting workability.
  - ♦ When well graded the voids are minimum.

d) Test on aggregates

Flakiness and Elongation Index (§ IS 2386)	➢ Flaky aggregates are those which have least lateral dimension **less than 0.6 times** of mean dimension of sample. $FI = \frac{weight\ of\ agg.\ passing\ thickness\ gauge}{total\ weight}$ ➢ Elongated aggregates are those having their longest dimension length

	$EI = \frac{weight\ of\ agg.\ retained\ on\ length\ gauge}{total\ weight}$
Toughness test or Impact value (§ IS 2386 IV)	➢ The aggregate impact value gives a relative measure of the resistance of aggregate to sudden shock or impact. ➢ 14kg hammer dropped from 38cm height for 15 number of blows. ➢ The crushed aggregate is then removed from the cup and the whole of it is sieved on 2.36 mm IS sieve until no further significant amount passes in one minute. $\text{AIV} = \frac{\text{fraction passing}}{\text{total weight}}$
Aggregate Abrasion test (§ IS 2386)	➢ The abrasion value of coarse aggregate may be determined by either Deval Machine or **Los Angles machine**. ➢ In LA machine, the abrasive charge consists of cast iron spheres approximately 48 mm in diameter and each weighing 390 and 445 g. ➢ It measures resistance against wear and tear. Sample is filled inside a rotating drum with charges, steel balls. And rotates at a speed of 20 to 33 rev/min. and total of 500 revolutions. ➢ Crushed sample is passed through 1.7mm sieve and weight of finer content is determined ➢ AAV < 30% for pavement and < 50% for other construction $\text{AAV} = \frac{\text{fraction passing}}{\text{total weight}}$
Crushing value	➢ Gradual load of 40 tones is applied at rate of 4 ton/min ➢ Crushed aggregate is then passed over 2.36mm sieve $\text{ACV} = \frac{\text{fraction passing}}{\text{total weight}}$

3. Water

a) Code recommendations

- Water used in concrete for mixing and curing should be free from injurious amount of oil, grease, sugar, organic contents, acids, alkali salts etc.
- Generally, water available at site is preferred for construction but
  - ♦ Variation of strength should not be more than 10%
  - ♦ Variation in setting time 30min as compared to normal water
- pH should not be less than 6

b) Amount of water for hydration

- Cement as a whole require about 23% of water by weight for complete hydration, but practically the amount of water added will be more because some water will be entrapped in voids by capillary action and internal layer spaces, generally 15% extra water is added. (**38%**)

4. Lime

a) Introduction

- The raw material for manufacturing of lime (CaO) is calcium carbonate which is obtained by the calcination of lime stone.
- Lime can also be obtained by the calcination of shell, coral, chalk and other calcareous substances.
- Corals and shells are sea animals. White chalk is a pure limestone whereas *kankar* is an impure limestone. Coral lime is claimed to be purest source of lime.

b) Impurities

- Hydraulicity is the ability of lime to set under water, in damp locations where free circulation of air is very less. This hydraulicity is imparted in lime by many impurities but in controlled manner.
- Clay: (8-30%) increases setting and decreases slaking.

- Soluble silicates of aluminium, magnesium, calcium imparts hydraulicity
- Magnesium carbonate: it gives better slaking, setting and good strength.
- Sulphate: they give better setting but retards slaking.
- MgO: (5%) gives better hydraulicity

c) Types of lime

Quick Lime	Pure lime, generally called quick lime is a shite oxide of calcium. (magnesium oxide gives brownish tinge) It is called caustic lime. It is capable of slaking with water and has no affinity for carbonic acid. ➢ Used in places of aesthetic appearance, white washing, plastering
Fat Lime	Has calcium oxide component and sets and hardens by absorption of CO_2 from atmosphere. ➢ For both pure and Fat lime slaking is vigorous and volume becomes 2-3 times. ➢ It sets slowly in contact with air, and hence is not suitable for thick walls or in wet climate. ➢ Specific gravity of pure lime is about 3.4. ➢ If kept under water, fat lime does not loose its plasticity and consequently does not set and hard. Fat lime finds excessive use in making mortar, matrix for concrete, base for distemper and in white wash, manufacturing of cement and metallurgical industry.
Hydraulic Lime	It is a product obtained by moderate burning (900º-1100ºC) of raw lime stone which contains small portions of clay (silica and alumina) 5-30% and iron oxide in chemical combination with calcium oxide content (CaO +MgO 70-80%) with MgO less than 5%. Depending upon percentage of clay, hydraulic lime is classified as ➢ *Feebly hydraulic* ➢ *Moderately hydraulic* ➢ *Eminently hydraulic*: slakes with difficulty and setts quickly 2hrs. used in damp places and oil structures.
Hydrated Lime	When quick lime is finely crushed, slaked with a minimum amount of water, and screened or ground to form a fine homogenous powder the product is hydrated lime.
Poor Lime	It consists of CaO + MgO $<$ 70% with MgO $<$ 5% and clayey impurities of more than 30% in the form of silica, alumina and iron-oxide. It sets on absorbing oxygen from atmosphere. ➢ Slaking requires more time and so it hydrates slowly. Its expansion is less than that of fat lime. ➢ It makes thin paste with water. ➢ Setting and hardening is very slow. ➢ The colour varies from yellow to grey. ➢ It gives poor mortar and is recommended for less important structures.

d) Uses of lime

- Extensively used with cement in mortars to enhance its properties, water retentivity increases- shrinkage decreases- and smooth surface is obtained. Due to plastic nature of lime mortar becomes workable.
- Used in making paints, glass manufacturing, cement manufacturing, soil stabilization, metallurgical processes, water treatment, in masonry, plastering.

e) Tests

- Fineness test (IS 6932 part 4)
- Determination of residue on slaking of quick lime (IS 6932 part 3)
- Workability test (IS 6932 part 8): test conducted on flow table and a truncated conical mould.

- Setting time test
- Soundness test (IS 6932 part 9): test is done to find the quality, the unsoundness of lime using Le-chatelier apparatus.
- Popping and pitting test (IS 6932 part 10)
- Volume yield of quick lime (IS 6932 part 6)
- Transverse strength test (IS 6932 part 7)
- Compressive strength test (IS 6932 part 7)

5. Mortar

a) Introduction

- Function of sand is to increase the strength, increase bulk volume, increase surface area on which mortar can be applied, reduce shrinkage and produces uniform setting.

b) Classification of mortar

- Mortars with unit weight less than or equal to 15 kN/m^3 is called light weight mortars. It is prepared using sawdust, asbestos fibers, light weight pozzolanas along with suitable binding material.
- Normal weight of mortar is 18-19 kN/m^3

Grade	H1	H2	M1	M2	M3	L1	L2
Strength MPa	>10	6–7.5	3–6	2–3	1.5	0.7	0.5

- Refractory mortars are prepared using high alumina cement along with crushed powder of fire bricks.

c) Lime mortar is made by mixing lime, sand and water. Lime used for mortar may be fat lime or hydraulic lime.

- Lime mortars have plasticity and placability, good cohesion with other surfacings and little shrinkage. They harden and develop strength very slowly continuously gaining strength over long period.

6. Pozzolanas

a) Activity of pozzolana

- When mixed with OPC the silica of Pozzolana combines with the free lime released during the hydration of cement. This action is called *Pozzolanic action*.
- The pozzolanic activity is due to the presence of *finely divided glassy silica* and lime which produce CSH similar to as produced during hydration of OPC and contributes to development of strength.

b) Different Pozzolana and their use

Fly ash (IS 3812) $SiO_2 + Al_2O_* + Fe_2O_*$	➢ It is the residue from the *combustion of pulverized coal* collected by mechanical orelectrostatic separator. ➢ Carbon content should be as low as possible and the fineness of fly ash should be ashigh as possible. Silica should be present in finely divided state. ➢ It reduces segregation and bleeding. ➢ The fly ash obtained from ESP may have a specific surface of 350 to 500 m^2/kg. ➢ Slow gain of strength, reduced permeability and increased setting time. ▪ **As part replacement of cement** Replacement up to 15 to 30% leads to lesser early strength, but once sufficient calcium hydroxide has been liberated, the rate of development of strength increases and equals in one to three months. A fine grinding of silica and high temperature curing increase the reactivity of pozzolana. The part replacement leads to increased workability, which can be used to reduce water content and inturn increase strength. ▪ **As part replacement of fine aggregates** This substitution of fly ash for sand has a beneficial effect on the strength even atearly ages, but is rather *uneconomical*

	This replacement enables the strength at a specified age to be equaled depending on the water content.
Granulated Blast-Furnace slag (IS 12089)	➢ It is a byproduct obtained while smelting iron ore in blast furnace. The floating impurities, containing mainly lime, silica and alumina. By rapid cooling of the slag glassy pallets are produced, which are further ground to produce GGBS. ➢ It is blended with OPC to produce Portland blast furnace slag cement < 65% ➢ Early strength is less but final strength is comparable. Used in mass concreting due to less heat of hydration, refined pore structure, reduced permeability and improved resistance to sulphate attack. ➢ The effect of blast furnace slag on the workability are much less than those of fly ash due to lesser specific surface of $325 \pm 25\ m^2/kg$ Improved workability, resistance to chemical attack and protection provided to reinforcement that make it suitable for reinforced concrete and prestressed concrete.
Silica fume	➢ It is also called micro silica, is a light to dark grey cementitious material composed of at least 85% ultra-fine amorphous non-crystalline (glassy) spherical silicon dioxide particles. ➢ The individual particles are extremely fine, $1/50^{th}$ size of an average Portland cement particle with SSA of 15000 m^2/kg. ➢ The effect of silica fume can be explained through two mechanisms- the pozzolanic reaction and micro filler effect. ➢ The extreme fineness of silica fume allows it to fill or pack the microscopic voids between cement particles and especially in the voids at the surface of the aggregates and fill all the available space.

7. Concrete

a) Classification based on bulk density

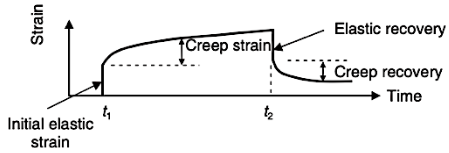
Super heavy	> 2500 kg/m^3
Dense	1800-2500 kg/m^3
Light weight	500-1800 kg/m^3
Extra light weight	< 500 kg/m^3

b) Methods of curing

- *Water curing* is done by coving the concrete surface with gunny bags and then sprinkling water over them regularly. Also, can be done by ponding, spraying and sprinkling.
- *Steam curing* is done by artificial heat while concrete is maintained in moist condition. This is called accelerated curing, because of increased rate of strength development.
- Curing by infra-red radiation.
- *Electrical curing*, by passing alternating current of low voltage and high amperage.
- *Chemical curing* by preventing evaporation of moisture from concrete

c) Mechanical properties

Modulus of elasticity	➢ *Static modulus of elasticity* It is defined as slope of stress strain curve for concrete under uniaxial tension or compression loading. But this curve for concrete is not straight at any point, the modulus of elasticity is found out with reference to tangent drawn to the curve at origin this is called *initial tangent modulus*. It gives satisfactory result at low stress values only. *Secant Modulus* is most commonly used, it gives slope of the line drawn connecting a specific point on curve to origin of curve. ➢ Dynamic modulus of elasticity It can be found by subjecting the concrete member to longitudinal vibration

Behavior under constant load- Creep	Constant load or stress is a very common occurrence, e.g. the stress due to the self-weight of a structure. Materials respond to this stress by an immediate straindeformation, normally elastic, followed by an *increase in strain with time*, called***creep.***  ➢ an initial elastic strain on stress application (related to the stress bythe modulus of elasticity) ➢ an increase in this strain due to creepduring the period of constant stress – fairly rapid at first but then at a decreasing rate ➢ an immediate elastic recovery on stress removal, often similar in magnitude tothe initial elastic strain

d) Strength Test on concrete (IS 516)

Compression test	➢ Test specimen cube of dimension 150 × 150 × 150 mm. ➢ Filled in 3 layers with 35 tamping in each layer. ➢ Average of three values is taken as compressive strength of concrete of the batch, provided individual variation is not more than ± 15 percent of average.
Flexure test	➢ The flexural tensile strength test is performed to estimate the tensile load at which concrete may crack. This is an indirect test for assessing the tensile strength of concrete. ➢ Modulus of rupture $\frac{Pl}{bd^2}$ — 200mm < a $\frac{3Pa}{bd^2}$ — 170mm < a < 200mm a – is the distance b/w line of fracture and nearest support, b, d are width and depth of specimen and l is span (150 × 150 × 700 mm)
Split tensile strength test (IS 5816)	➢ Due to difficulty in applying uniaxial tension to a concrete specimen, the tensile strength is determined by indirect methods. ➢ Standard test cylinder 300 × 150 mm diameter is placed horizontally between the loading surface. The compression load is applied diametrically and uniformly along the length of cylinder. $$\sigma_T = \frac{2P}{\pi DL}$$ Limitations ▪ The test calculates maximum tensile stress assuming line loads and uniformly distributed tensile stress. ▪ The strength of specimen depends upon the diameter of the specimen and hence not necessarily a material property.

e) Factors influencing strength of concrete

- Size of test specimen
- Type of stress situation that may exist
- Size of specimen relative to maximum size of aggregate
- Moisture condition of specimen
- Air voids
- Rate of loading

f) Maturity

- The strength of concrete depends upon both the time as well as temperature during the early period of gain in strength. The maturity of concrete is defined as the summation of product of time and temperature.

$$M = \sum (T - T_{\text{ç}}) \times \Delta t$$

  - $T_{\text{ç}}$ datum temperature 11ºC
- ***Strength-maturity Relationships*** Based on the temperature history of the concrete, one of the popular strength-maturity relationships proposed by Plowman (1956) is

$$f = a + b \log_{\text{Fç}}(M \times 10^{-*})$$

  - f is % strength for maturity M

g) Workability

- Workability is referred to as the ease with which a concrete can be transported, placed and consolidated without excessive bleeding or segregation. It can be defined as the ease with which concrete can be fully compacted with regard to mode of compaction and place of deposition.
- Factors affecting workability
  - Water content, Mix proportions, Aggregate size, Shape of aggregate, Surface texture, Grading of aggregates, Admixtures
- Measurement of workability (§ IS 1199)

Slump test	Bottom diameter 200mm, top diameter 100mm and height 300mm Mould is filled in with fresh concrete in four layers, each tamped 25 strokes ➢ After the mould is removed, the concrete subsides and this subsidence is referred as slump of concrete. The difference between the height of mould and the highest point in mm is taken as slump of concrete. ➢ A shear slump indicates non-cohesive concrete and may lead to segregation, average value of slump is taken.
Compaction Factor test	Test is more precise and sensitive than slump test. Compacting factor is defined as the ratio of the weight of partially compacted concrete to the weight of fully compacted concrete
Vee-Bee consistometer method	The test determines the time required for transforming, by vibration, a concrete specimen in the shape of a conical frustum into a cylinder. The consistency of the concrete is expressed in VB degree which is equal to the recorded time in seconds.
Flow table test	This test is applicable for concrete having high workability. Frustum cone is placed on a flow table which is filled with concrete in 2 layers and lifted gently. Table is risen and dropped for height 12.5 mm, 15 times in 15 seconds. Diameter of spread is measured at least in 6 directions, and flow percentage is calculated. $Flow\% = \frac{average\ spread - 25}{25} \times 100$

h) Suggested range of workability (§ cl 7)

Placing condition	Degree of workability	Slump
*Blinding concrete**, shallow sections, pavement using pavers	Very low	Compaction factor (0.75 to 0.80)
Mass concrete, lightly reinforced section in slabs, beams, walls, columns, floors, hand placed pavements, canal lining, strip footing	Low	25–75
Heavily reinforced sections in slabs, beams, walls, columns, *slip form work***, pumped concrete	Medium	50–100
Trench fill, in-situ pilling, tremie concrete	High	75–100
	Very High	Flow measurement

- * *Concrete blinding* is the process of pouring a thin layer of concrete over the floor of a new building; this can be over the hardcore or over the foundation itself. The purpose of this is to seal in underlying material and prevent dirt and mud from interfering with the structure.
- ***Slip forming*, continuous poured, continuously formed, or slip-form construction is a construction method in which concrete is poured into a continuously moving form. Slip forming is used for tall structures, as well as horizontal structures, such as roadways.

i) **Non-Destructive testing** (§ cl 17.8)

- Non-destructive tests are used to obtain estimation of the properties of concrete in the structure. Non-destructive test provides alternatives to core tests for estimating the strength of concrete in a structure, or can supplement the data obtained from a limited number of cores. These methods are based on measuring a concrete property that bears some relationship to strength.
- The methods adopted includes following:
    - Pullout test: is more authentic than the concrete core test. A special shaped steel rod with one end enlarged is embedded in concrete in the form-work. After the concrete hardens the rod is pulled out and in so doing it comes out with a block of concrete.
    - Penetration test: a probe of diameter 6.5 mm and length 80 mm, is driven into the concrete by means of a precision powder charge. Depth of penetration provides an indication of the compressive strength of the concrete.
    - Ultrasonic pulse velocity test: (IS 13311) ultrasonic pulses are released from one of the transducers placed in contact with one of the surfaces of concrete, this pulse is converted into electric signal by a second electro-acoustical transducer, and the time taken by the pulse to travel is displayed digitally in instrument. This test is conducted to estimate strength of concrete, Homogeneity of concrete and Dynamic modulus of elasticity.
        - There must be smooth contact with surface under test, and a coupling medium such as a thin film of oil is mandatory.
        - Path length should be at least 30 cm to avoid error due to heterogeneity.
        - Plush velocity increases below freezing temperature, between 5 to 30 ^{o} C temperature velocity is independent of temperature.
        - The presence of reinforcing steel in concrete has an appreciable effect on pulse velocity.
    - ***Schmidt test hammer***: (IS 13311) The *rebound hammer* is a surface hardness tester for which an empirical correlation has been established between compressive strength and rebound number.
        - When the plunger of the hammer is pressed against the surface of the concrete, the spring controlled mass rebounds and the extent of the rebound depends upon surface hardness of concrete.
        - The test provides useful information for surface layer up to 30mm depth and is suitable for concrete having strength of 20-60 MPa
        - The concrete surface should be smooth and loose material should be ground off.
        - ***Factors influencing test results***
            - Mix characteristics like cement type, cement content and coarse aggregate type.
            - Member characteristics eg. Mass, compaction, surface type, age of concrete, moisture condition, stress state and temperature

j) Alkali aggregate reaction (§ cl 8.2.5.4)

- Some aggregates containing particular varieties of silica is susceptible to attack by alkalis (Na_2O and K_2O) originating from cement or other sources, producing an expensive reaction which can cause cracking and disruption of concrete. The damage to concrete from this reaction will normally only occur when all the following are present together:
    - A high moisture level, within the concrete.
    - A cement with high alkali content, or other sources of alkali.
    - Aggregate containing an alkali reactive constituent.

- When the service record of particular cement or aggregate combination are well established, and do not include any instances of cracking due to alkali-aggregate reaction, no further precautions is necessary. When the materials are unfamiliar, ***precautions*** should take on or more of the following forms:
  - Use of non-reactive aggregate from alternate sources.
  - Use of low alkali OPC having total alkali content not more than 0.6% (as Na_2O)
  - Further advantage can be obtained by use of fly ash (at least 20%) or granulated blast furnace slag as part replacement of OPC (at least 50%).
  - Measures to reduce the degree of saturation of the concrete during service such as use of impermeable membranes.
  - Limiting the cement content in the concrete mix and thereby limiting the total alkali content in the concrete mix.

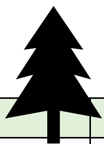
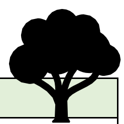
8. Admixtures

Accelerators	➢ Normally reduce the setting time, accelerate the rate of hydration of cement and consequently the rate of gain of strength. They are very useful for concreting in cold weather. ➢ Ex: $CaCl_2$, Silicates, Fluorosilicates, Triethanol amine
Retarders	➢ Normally increases the setting time and thus delay the setting of cement. Since these reduce the rate of hydration, more water is available and better is the workability. ➢ It is helpful in places where temperature is acting as an accelerator. Used in construction of oil wells. ➢ Ex: Gypsum, Sugar, Starch, Cellulose, Tartaric acid
Plasticizers	➢ The action of plasticizers is mainly to fluidify the mix and improve the workability of concrete, mortar or grout. The mechanisms involved are: *Dispersion* (by charge neutralisation, flocs breaks and water becomes free) *Retarding effect* (layer on cement particles inhibit hydration) ➢ It can reduce water requirement up to 15% ➢ Ex: Ligno sulphates, Carbohydrates, Carboxylic acid, Polyglycol ester
Super plasticizers	➢ Chemically different substance than plasticizers but nature of working is same as plasticizers. ➢ Reduces water up to 30% ➢ Ex: Modified Lignosulphates, Sulphonated Nepthaline formaldehyde (SNF), Sulphonated melamine formaldehyde (SMF)
Air entertainers	➢ Introduces million of air bubbles inside concrete. Air bubbles are tiny and non-collapsible act as a ball bearing, particles slide over each other, increasing workability. Lesser water content required, and resistance against frost action increases. Reduces segregation and bleeding. ➢ Concrete becomes light weight may lose strength, durability will be high. ➢ Ex: natural wood resins, fatty oil or acids, hydrogen peroxide, Aluminium powder.

9. Timber

a) Trees

- Exogenous: grows in outward direction.

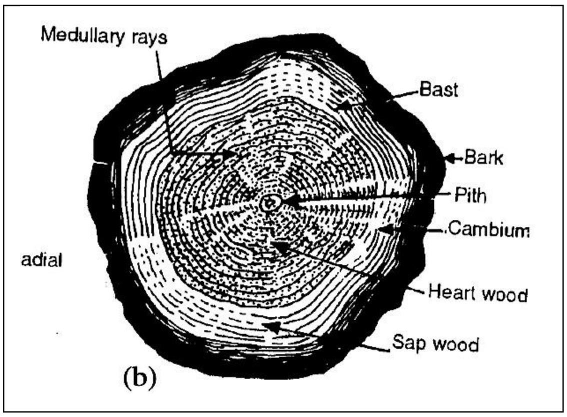
Conifers	Deciduous
➢ Trees have cone shaped leaves. ➢ These are evergreen trees ➢ They are soft, light in colour and weight, fibrous resinous in nature.	➢ These trees have broad leaves, and shade them in autumn and regrow in spring. ➢ Timber is hardwood, dark in color heavy weight and non-fibrous.

➢ Annual rings are clearly visible ➢ Limited use in engineering application ➢ Ex: Pine, Spruce, Chir, Deodar	➢ Modularly rays are visible ➢ Widely used in engineering application ➢ Ex: Teak, Sal, Mahogany, Babul, Oak

- Endogenous: these trees grow inwards
    - ♦ They have limited engineering value
    - ♦ They are hollow from inside
    - ♦ Ex: Bamboo, Cane, Palm

b) Structure of tree

- Pith
    - ♦ It is the oldest portion of the tree section which helps the tree to grow in young age. After sufficient duration it becomes hard and stable, it is inner most portion and is dark in colour.
- Heart wood
    - ♦ The wood around the pith which is also relatively dark in colour is known as heart wood, this is strong hard and stable which help the tree against any external forces and increases the stability of the tree.
- Sap wood
    - ♦ It is the portion of the wood between heartwood and cambium layer, recently converted to wood from sap, this doesn't have high strength and is relatively soft, this helps growth of tree along with cambium layer.
- Cambium layer
    - ♦ It is the outer layer, which is in fluid form, yet to be converted to wood. It contains sap, responsible for growth of the tree. This layer should not be exposed to atmosphere.
- Bark
    - ♦ It protects cambium layer from atmosphere. Inner bark is soft from outer bark.
- Medullary rays
    - ♦ These are thin fibers initiating from pith up to cambium layer in radial direction, hold the layers together and is responsible for transverse strength of tree section



c) Seasoning of timber

- At the time of felling of a tree, it contains a lot of moisture, and before using it for engineering purpose moisture needs to be removed, ***the process of moisture removal is called seasoning***. Water content is lowered to 10-12% by its dry weight.
- ***Fiber saturation point*** is that point of moisture removal when moisture from cell cavities has been removed, but not from cell walls.
- Methods

Natural seasoning	➢ Placed in a room covered form top, with sufficient spacing for air to pass through is provided. Duration is 3 to 6 months. This is not preferred as no control on natural agencies and drying is uneven, timber may get subjected to insects and fungi.
Boiling	➢ Boiling in water or exposing the wood to the action of steam spray is a very quick but expensive process of seasoning. ➢ Some chances of loss of strength and shrinkage is there.
Water seasoning	➢ The logs of wood are kept completely immersed in running stream of water, with their larger ends pointing upstream. Consequently the sap, sugar, and gum are leached out and are replaced by water. The logs are then kept out in air to

	dry. It is a quick process but the elastic properties and strength of the wood are reduced.
Kiln seasoning	➢ This method is adopted for rapid seasoning of timber on large scale to any moisture content. The scantlings are arranged for free circulation of heated air with some moisture or superheated steam. The circulating air takes up moisture required from wood and seasons it. ➢ For a successful kiln-seasoning the timber should be brought to as high a temperature as it will stand without injury before drying is begun; otherwise the moisture in the hot outer fibres of the wood will tend to flow towards the cooler interior. ➢ With kiln drying there is a little loss in strength of timber, usually less than 10 per cent. Also, the wood is more thoroughly and evenly dried, thus reducing the hygroscopicity of the wood.
Chemical seasoning	➢ An aqueous solution of certain chemicals have lower vapour pressures than that of pure water. If the outer layers of timber are treated with such chemicals the vapour pressure will reduce and a vapour pressure gradient is setup. ➢ The interior of timber, containing no salts, retains its original vapour pressure and, therefore, tends to dry as rapidly as if there had been no treatment. ➢ A chemically treated timber will exhibit fewer defects. ➢ Common salt or urea are generally used; the latter is preferred as the corrosive action of common salt is a drawback.
Electrical seasoning	➢ This method, uses high frequency alternating current. ➢ The logs are placed in such a way that their two ends touch the electrodes. Current is passed through the setup, being a bad conductor, wood resists the flow of current, generating heat in the process, which results in its drying. ➢ The drawback is that the wood may split.

d) Defects in timbers

Natural defects	➢ *Knots*: due to branching, reduce strength of timber and affects workability. ➢ *Twisted fibers*: due to twisting to tress due to natural forces. ➢ *Shakes*: these are longitudinal separations in the wood between annual rings. These reduce shear strength without much effect on compressive and tensile strength. Ex. cup shake, ring shake, star shake, heart shake, radial shake ➢ Foxiness: it is a sign of decay appearing in the form of yellow or red tinge or discoloration of overmatured trees.
Due to seasoning	Bow: bending along length Cup: bending along width Warping Twisting Splitting: separation of fibers through a piece of timber from one face to another.
Due to conversion	Diagonal grains Torn grains Wane defect: presence of any natural curved surface Chip marks

e) Diseases of timber

Sap stain	(***Blue stain***) due to action of fungi, sap is converted to blue colour
Brown rot	due to action of fungi on the ***cellulose*** of timber, it converts to brown colour.
White rot	fungi affect ***the lignin*** of timber and white rot is formed
Dry rot	It is decomposition of felled timber caused by the action of various fungi. The fungus reduces fibres to fine powder, the timber loses its strength. This disease is highly infectious and causes tremendous destruction. It occurs when the timber is

	imperfectly seasoned ***and placed in a moist, warm and confined atmosphere having no free access of air.***
Wet rot	When timber is ***subjected to alternate wet and dry conditions***, decomposition of tissues takes place. This is not caused by fungal attack. In a living tree, it is set up by the access of water through wounds in the bark and causes the decomposition of sap and fibres of the tree. This may also occur when timber is seasoned by exposing it to moisture. To avoid wet rot, well-seasoned timber is used with preservatives and paints.

f) Decay of timber

- Timber is affected by destructive elements, such as weathering, chemical attack, fungi, insects or rodents.

Fungal and bacterial attack	Bacterial do not cause any serious damage to timber, except for some discolorations. Fungi are a system of plant organism which live in and attack timber causing rot and decay. They secret solvent chemicals and enzymes, which makes wood brittle and weak. Symptoms are discoloration, abnormal mottled appearance, roughness of surface and presence of soft spots of intense discoloration.
Insects	Termites or white ants: they excavate the wood at the centre leaving the outer shell intact. Beetles they cause rapid decay by converting them into fine powder.
Rodents	Rodents are capable of penetrating both wood and concrete. All the openings or passages should be closed in a rat-tight manner by fixing metal sheets over the lower part of doors.

g) Preservation of timber

- It is done to make the timber more durable against conditions which can deteriorate the timber. Preservative treatments are:

White Ants	➢ Copper-chromate-arsenic composition is made of three chemicals. Arsenic-pentaoxide $As_2O_Q \cdot 2H_2O$ 1 part Copper sulphate $CuSO_3 \cdot 5H_2O$ 3 part Sodium or potassium dichromate $(Na/K)_2\ Cr_2CO_{í}$ 4 part • The preservative is in the form of a powder and is used with water. Six parts of this powder is mixed with 100 parts by weight of water. The solution is applied in two coats. The timber is then allowed to dry for six weeks. This treatment renders the timber immune to the attacks of white ants and is known as *AsCu treatment.* ➢ *Solignum paints*: it is commercial name of paint used for preserving wood against white ants
Water	Oil paints Coal tar: it has non-decorative effect, gives bad smell, so less preferred.
Insects and Fungi	➢ Creosote oil penetration through **Bethel's process**. This doubles the life of timber. This is used in preservation of piles, railway sleepers, poles etc. ➢ Using chemicals: $CuSO_3$, $ZnCl_2$, mercury chloride, sodium fluoride
Fire	➢ Sir Abel's process: • The surface of wood is painted by a weak solution of ***sodium silicate***. • Thereafter slaked lime solution of the consistency of a paste is applied followed by the application of concentrated solution of sodium silicate in two coats. Second being applied after 6hrs of the first coat. ➢ Coal tar ➢ Antipyrines (chemicals having fire resistance)

	Ex: Borax, Boric acid, Ammonium phosphate, Sodium arsenate, zinc chloride

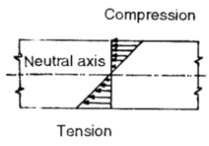
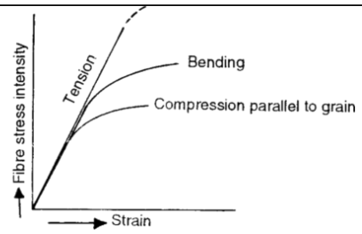
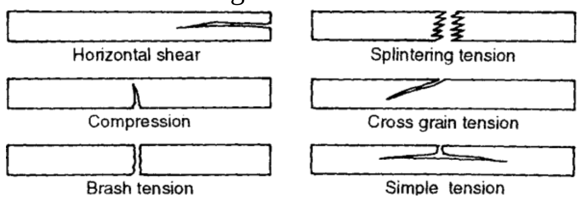
- Various Treatment Processes (IS 401)

Surface application	Is done either by spraying, dipping or by brushing the preservative. At least two coats should be applied after drying on first.
Soaking treatment	Consists of submerging timber in preservative solution for sufficiently long period until required absorption is obtained.
Hot and cold process	Timber is submerged in the preservative solution, then heated to 90º to 95º C and maintained at this temperature for a suitable period. It is then allowed to cool.
Boucherie process	Sapwood of almost all green timbers with bark on, can be treated using any inorganic water-soluble preservatives by this process. The wood is attached to the hose pipe and connected to reservoir containing preservative. Due to hydrostatic pressure, the sap in the wood is displaced.
Full cell or Bethel process	It is essentially a pressure process and is used when maximum absorption of preservative is desired. The timber charge is introduced in a tightly closed cylinder, a vacuum of 560mm mercury is created and maintained for half an hour. After that preservative is introduced and positive pressure is applied until desired absorption is achieved. The preservative is then withdrawn and finally a vacuum for 15 minutes is again applied, to free timber form dripping preservative.
Empty cell process	Also known as pressure process and is aimed at a maximum penetration of preservative with minimum net retention. Two processes commonly used are: ➢ *Lawry process*: timber is loaded, followed by filling with preservative. Positive pressure is applied until required absorption is obtained. Pressure is released, cylinder is drained and finally, a vacuum is applied. ➢ *Rueping process*: cylinder is charged with timber and closed. An air pressure is applied for specified period and is maintained during subsequent filling up the cylinder with preservative. After filling positive pressure is applied until desired absorption followed by vacuum as done in full cell process. This process is recommended for treating timber of mixed species and timber containing sapwood and heartwood.

h) Properties of wood

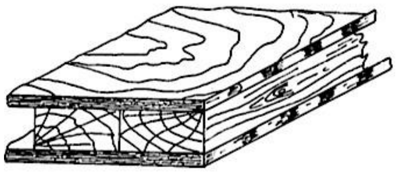
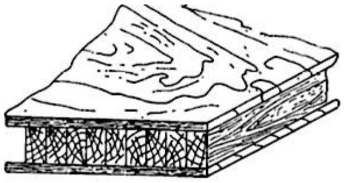
- Density and specific weight: all mechanical properties of wood are related to its density. The true specific gravity of wood is approximately equal for all species and averages 1.54.
- Moisture movement: movement of water due to variations in moisture content is greater in the plane of the annual rings.
- Shrinkage: linear shrinkage 0.1- 0.3%, radial shrinkage 3-6%, tangential 7-12%, in general, the radial shrinkage is 60% of the tangential and volumetric shrinkage is 1.6 times the tangential.
- Mechanical properties, stress strain relationships
  - ♦ For direct tension, direct compression and bending stress intensities *parallel to the grain*, direct compression and bending proportional limit is in the vicinity of 65 to 75% of the ultimate strength.
  - ♦ Modulus of elasticity of the grain is practically the same in direct tension, direct compression and bending.

Compressive strength	When subjected to compressive force acting parallel to the axis of growth, wood is found to be one of the strongest structural material. Columns and posts are therefore, often made of it. Compressive strength perpendicular to fibers of wood is much lower. ➢ A knowledge of the compressive strength is of value in estimating strength in bending since experiments have demonstrated that the yield point of wood beams is determined by the compressive strength.

	 
Tensile strength	The tensile strength of wood parallel to the grain is higher than any other kind of stress. It is difficult to design end connections, where tensile strength is used, so tension members are rarely used. Knots, shakes etc. reduce tensile strength of wood.
Bending strength	Woods withstands static bending well, owning to which it is widely employed for elements of buildings. 

i) Wood products

Veneers	➢ The primary process in the manufacture of wood based products is veneering which produces thin sheets of wood known as *veneers*. The thickness of veneers varies from **0.4 to 0.6 mm**. In no case it should exceed 1 mm. ➢ The most suitable wood for this purpose is walnut. However other species like teak, sissoo, rose wood, etc. are also used. ➢ The logs to be used for this purpose are kept in wet storage to avoid end splitting and are softened by heating with hot water or steam and the bark is removed. The log is then cut to veneers. ➢ Depending on the cutting process, the veneers are classified as rotary veneers and sliced veneers. These are used in the manufacture of plywood and other laminated boards.
Plywood	➢ A wood panel glued under pressure from an odd number (usually 3 to 13) of layers of veneers is known as plywood. ➢ The outer most veneer sheets in a plywood panel are called faces. The interior plies which have their grain directions parallel to that of the faces are termed as *core/centre*. Other piles which have grain directions perpendicular to that in the face are termed as *cross bands.* ➢ They may be classified upon direction of grains in the plies and on the types of adhesive used. Alternate plies oriented at 30º or 60º in star plywood. 45º in diagonal plywood. When plies are bonded together with water-soluble glues, interior grade plywood is obtained and when bonded with phenol formaldehyde adhesive it is identified as exterior grade plywood which is completely waterproof. Advantages ➢ It has good strength both along as well as across the grains. ➢ The wood shrinks or swells more across the grains. Since plywood has cross-grained construction, the tendency to shrink or swell is reduced. ➢ It has better splitting resistance due to the grains in adjacent veneers in cross direction as such nailing can be done very safely even near the edges. ➢ Plywood can be curved into desired shapes. Uses: These are extensively used for partitions, ceilings, doors, concrete formwork, plywood boards etc.
Fiber Boards	These boards built up of ***felting from wood or vegetable*** (wood wastes, waste paper, agricultural wastes, etc.) are classified by the process of their moulding.

	If the boards are moulded by ***wet process***, the main bond is by the felting of woody fibres and not by added glue. For the boards moulded by ***dry process***, the bond between the pre-dried fibres is improved by adding 4–8% of synthetic resin. For better performance wood preservatives and other admixtures are often added to the pulp. Fibre boards are manufactured in various densities like soft, medium and hard. The soft boards are ***used for walls and ceilings***. Medium boards find their application in ***panelling, partition walls, doors and windows***. *Hard boards* have one surface smooth and the other one textured. These have higher densities, better mechanical properties, and improved moisture and termite resistances.
Batten boards	Batten boards have core made up of 80 mm wide wood piece, forming a slab glued between at least two surface veneers.
Lamin Boards	They have a core strips, each not exceeding 7 mm in thickness, glued together to form slab which in turn is glued between two or more outer veneers. The direction of the core block run at right angles to that of the adjacent outer veneers.  Fig. 4.27 Batten Board  Fig. 4.28 Lamin Board

10.Bricks

a) Classification of Ordinary bricks

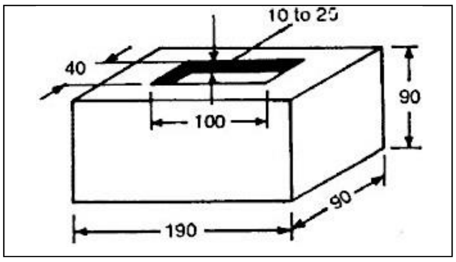
First class brick	➢ These are thoroughly burnt and are of deep red, cherry or copper colour. ➢ The surface should be smooth and rectangular, with parallel, sharp and straight edges and square corners. ➢ These should be free from flaws, cracks and stones. These should have uniform texture. No impression should be left on the brick when a scratch is made by a finger nail. ➢ The fractured surface of the brick should not show lumps of lime. A metallic or ringing sound should come when two bricks are struck against each other. ➢ *Water absorption should be 12–15%* of its dry weight when immersed in cold water for 24 hours. The crushing strength of the brick should not be less than 10 N/mm^2. ➢ They are recommended for pointing, exposed face work in masonry, flooring and reinforced brick work.
Second class brick	➢ Small cracks and distortions are permitted. ➢ A little higher water absorption of about 16–20% of its dry weight is allowed. ➢ The crushing strength should not be less than 7.0 N/mm^2. ➢ They are used in all important and unimportant hidden masonry work and RCC structure.
Third Class Bricks	➢ They are unburnt. ➢ They are soft and light-coloured producing a dull sound when struck against each other. ➢ Water absorption is about 25% of dry weight. It is used for building ***temporary structures***.
Fourth Class Bricks	➢ They are ***overburnt*** and badly distorted in shape and size and are ***brittle*** in nature. ➢ The ballast of such bricks is used for foundation and floors in lime concrete and road metal.

b) The Indian Standards (IS 1077)

- has ***classified*** the bricks on the basis of ***average compressive strength***.
- The minimum compressive strength has been kept at 3.5 MPa.
- The burnt clay bricks having compressive strength more than 40 MPa are known as heavy duty bricks and are used for heavy duty structures such as bridges, foundations for industrial buildings, multi-storey buildings, etc. The water absorption for such bricks is limited to 5%.
- Each class of bricks as specified on compressive strength is further divided into subclasses A and B based on ***tolerances and shape***.
  - Subclass-A bricks should have smooth rectangular faces with sharp corners and uniform colour.
  - Subclass-B bricks may have slightly distorted and round edges.

c) Dimensions

- The length and width and height of a brick are interrelated as
  - $\text{Length of brick} = 2 \times \text{Width of brick} + \text{thickness of mortar}$
  - $\text{Height of brick} = \text{width of brick}$
- Size of standard brick (**Modular brick**) is 19x9x9 cm and 19x9x4 cm. when placed in masonry it becomes 20x10x10 cm.
- However, the bricks available in most part of the country still are 9”x4.5”x3” and are known as field bricks. Weight of such a brick is 3 kg.
- Frog
  - An indent called frog, 1-2 cm deep, is provided for 9 cm high bricks. The size of frog should generally be 10x4x1 cm. The purpose of providing frog is to form key foe holding the mortar.
  - Frog is not provided in 4cm high bricks and extruded bricks.



d) Ingredients

Silica	50-60% It enables the brick to ***retain its shape and imparts durability***, prevents shrinkage and warping. Excess of silica makes the brick brittle and weak on burning. A large percentage of sand or un-combined silica in clay is undesirable. However, it is added to decrease shrinkage in burning and to increase the refractoriness of low alumina clays.
Alumina	20-30% It absorbs water and ***renders the clay plastic***. If alumina is present in excess of the specified quantity, it produces ***cracks in brick on drying***. Clays having exceedingly high alumina content are likely to be very refractory.
Lime	5% Reduces the shrinkage on drying. Causes ***silica in clay to melt on burning*** and thus helps to bind it. In carbonated form, lime lowers the fusion point. Excess of lime causes ***the brick to melt and the brick loses its shape***. Red bricks are obtained on burning at considerably high temperature (more than 800°C) and buff-burning bricks are made by increasing the lime content.
Magnesia	It rarely exceeding 1 per cent, ***affects the colour and makes the brick yellow***, in burning; it causes the clay to soften at slower rate than in most case is lime and reduces warping.
Iron oxide	7% ➢ Gives ***red colour on burning*** when excess of oxygen is available and dark brown or even black colour when oxygen available is insufficient, however, excess of ferric oxide makes the brick dark blue. ➢ Improves impermeability and durability. Tends to lower the fusion point of the clay, especially if present as ferrous oxide. ➢ Gives strength and hardness.

e) Harmful substances in brick earth

Lime	Excess of lime changes colour of brick from red to yellow. Lime present in lumps, absorb moisture, swells and causes disintegration of the bricks.
Pebbles, grits	They do not allow the clay to be mixed thoroughly and spoil the appearance of the brick. Bricks with pebbles and gravels may crack while working.
Iron pyrite	Iron pyrites tend to oxidise and decompose the brick during burning. The brick may split into pieces.
Alkalis	They melt the clay on burning and make the bricks unsymmetrical. On exposure to moisture efflorescence occurs and spoils the appearance.
Organic matter	Organic matter gets charred and leave pores making the bricks porous; the water absorption is increased and the strength is reduced.
Carbonaceous material	Causes black core and bloating.
Sulphur	It causes formation of spongy, swollen structure in the brick and the brick will be decoloured by white blotches.

f) Defects in brick

Over burning	Over burning produces soft molten mass and brick loose their shape. Such bricks are not used for construction works.
Under burning	The clay is not softened because of insufficient heat and the pores are not closed. This leads to higher degree of water absorption and less compressive strength.
Bloating	Spongy swollen mass on brick surface because of carbonaceous material and sulphur.
Black core	Because of bituminous matter or carbon improper burning occurs.
Efflorescence	Because of alkalis present in brick, when bricks comes in contact with water, they crystalize on surface and appear as grey or white powder patches.
Chuffs	The deformation of the shape of bricks caused by the rain water falling on hot bricks.
Checks	This is because of lumps of lime or excess water. Expansion caused by lime nodules and shrinkage by water on drying causes cracks.
Spots	Iron sulphide, results in dark spots, though not harmful, unsuitable for masonry work.
Blisters	It is due to air imprisoned during moulding.
Laminations	These are caused by entrapped air in the voids of clay. Laminations produce thin lamina on the brick faces which weather out on exposure. Such bricks are weak in structure.

g) Manufacturing

- Preparation of clay
    - ***Unsoiling***: about 20 cm of top layer of earth, normally containing stones, pebbles, gravel, roots etc. is removed after clearing the trees and vegetation.
    - ***Digging***: proportions of additives such as fly ash, sandy loam, rice husk ash etc. are spread over the plane ground. The soil mass is then manually excavated, puddled, watered and left over for weathering and subsequent processing.
    - ***Weathering***: soil is heaped on level ground in layers of 60-120 cm, and left to be exposed to weather for at least one month. This is done to develop homogeneity in the mass of soil and to eliminate impurities which get oxidised. Soil is kept wet by spraying water as often as necessary and is turned at least twice.
    - ***Blending***: the earth is then mixed with sandy and calcareous earth in suitable proportions to modify the composition of soil. Moderate amount of water is mixed so as to obtain right consistency for moulding. The mass is then mixed uniformly with spades.
    - ***Tempering***: it consists of kneading the earth with feet so as to make the mass stiff and plastic. It can be done in pug mills and the operation is called ***pugging***.
- ***Moulding***: it is the process of giving required shape to the brick from the prepared brick earth.
    - Hand moulding

        - ***Ground moulding***: in this process, the ground is levelled and sand is sprinkled on it. The moulded bricks are left on the ground for drying.
        - ***Table moulding***: the bricks are moulded on *stock boards* nailed on the moulding table, which has projection for forming frog. A thin board *pallet* is placed over the mould and then smartly lifted off the stock board and inverted so that the moulded clay along with the mould rests on the pallet. The mould is then removed and brick is carried to the drying site.
    - Machine moulding
        - *Plastic method*: the pugged, stiffer clay is forced through a rectangular opening of brick size by means of an auger. clay comes out of the opening in the form of a bar. The bricks are cut from the bar by a frame containing of several wires. This is quick and economical process.
        - ***Dry-press method***: the moist, powdered clay is fed into the mould on a mechanically operated press, where it is subjected to high pressure and the clay in the mould takes the shape of bricks. Such pressed bricks are more dense, smooth and uniform than ordinary bricks. They are burnt carefully as they are likely to crack.
- Drying
    - Green bricks contain about 7-30% moisture depending upon the method of manufacturing. The object of drying is ***to remove the moisture to control the shrinkage and save fuel and time during burning***. The moisture content is brought down to about 3% under exposed conditions within 3 to 4 days. Thus, the strength of the green bricks is increased and the bricks can be handled safely.
- Burning:
    - Burning of clay may be divided into three main stages
    - *Dehydration* (400–650ºC): this is also known as water smoking stage. Water left after drying is driven off and clay loses its plasticity. Carbonaceous matter is burnt. Hydroxides are dehydrated and carbonates are decarbonated. Too rapid heating causes cracking or bursting of brick.
    - *Oxidation Period* (650–900ºC): during this period, remainder of carbon is eliminated and ferrous iron is oxidised to ferric form. The removal of sulphur is completed. In order to avoid black or spongy cores, oxidation must proceed at such a rate which allows changes to occur before the heat becomes sufficient to soften the clay and close its pore. Sand is often added to the raw clay to produce a more open structure and thus provide escape of gasses generated in burning.
    - *Vitrification*: – to convert mass into glass like substance – the temperature ranges from 900-1100ºC for low melting clay and 1000-1250ºC for high melting clay. Vitrification period may be further divided into (i) incipient vitrification, at which the clay has softened sufficiently to cause adherence (ii) complete vitrification, is well marked by maximum shrinkage (iii) viscous vitrification, produced by a further increase in temperature which results in a soft molten mass, a gradual loss in shape and a glassy structure after cooling.
- Clamps (Pazawah)
        - A clamp is a temporary structure whereas kiln is a permanent one.
        - The bricks and fuel are placed in alternate layers. The amount of fuel is reduced successively in the top layers. Each brick tier has 4–5 layers of bricks. Some space is left between bricks for free circulation of hot gasses.
        - The top and sides of the clamp are plastered with mud. Then a coat of cow dung is given, which prevents the escape of heat. The production of bricks is 2-3 lacs and the process is completed in six months. This process yields 60% first class bricks.
- Kilns
    - Intermittent kiln: process of burning is discontinuous.

- After loading the kiln, it is fired, cooled and unloaded and then the next loading is done. Since the walls and sides get cooled during reloading and are to be heated again, there is wastage of fuel.
    - Down drought
    - Up drought
- Continuous kiln: the process of burning is continuous.
    - Bricks are stacked in various chambers; wherein the bricks undergo different treatments at the same time.
    - When the bricks in one of the chambers is fired, the bricks in the next set of chambers are dried and preheated, while bricks in the other set of chambers are loaded and in the last are cooled.
        - *Bull trench kiln*
        - *Hoffman's kiln*
        - Tunnel

h) Fire clay brick or Refractory Bricks

- Introduction
    - Fire clay is a term, loosely applied, to include those sedimentary or residual clays which vitrify at a very high temperature and which, when so burnt, possess great resistance to heat.
    - These are pure hydrated silicates of alumina and contain a large proportion of silica 55–75%, alumina 20–35%, iron oxide 2–5% with about 1 per cent of lime, magnesia and alkalis.
    - The greater the percentage of **alumina**, the more refractory the clay will be. Fire clays are capable of resisting very high temperatures up to 1700°C without melting or softening and resist spalling.
    - Fire-clay bricks are made from fire-clay. The process of manufacturing is as of an ordinary brick, burnt at very high temperatures in special kilns (**Hoffman's kiln**).
    - These are used for lining blast furnaces, ovens, kilns, boilers and chimneys.
    - The colour is whitish yellow or light brown, water absorption varies from 4-10%, minimum average compressive strength is 3.5 N/mm^2
- Acid refractory bricks
    - Consists of **silica bricks** (95-97% silica and 1-2% lime), used in lining furnaces having siliceous and acidic slag, steel industry and coke oven. They have tendency to spall during rapid temperature change.
- **Basic refractory brick**
    - It consists of magnesia bricks and bauxite bricks. They are highly resistant to corrosion and are used for lining furnaces having basic slag.
    - Used in copper metallurgy and basic open hearth.
        - Magnesite, dolomite and bauxite
- Neutral refractory bricks
    - Consist of **chromite bricks** (50% chrome and iron ore containing 30% iron oxide and bauxite containing 15% alumina and 5% silica).
    - Chrome magnesite bricks, spinel and Fosterite are also neutral bricks.
    - The neutral refractory bricks are suitable at places where acidic and basic linings are to be separated, e.g. for lining copper reverberatory furnace.

i) Autoclave bricks

- These are manufactured in autoclave where temperature as well as pressure is applied hence compressive strength of bricks increases, they are light in weight but have very high strength and lesser thermal conductivity.

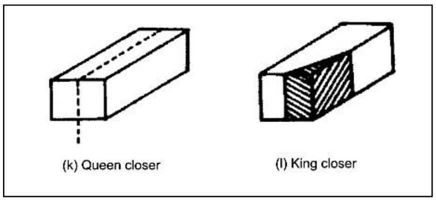
j) Burnt clay Brick (IS 2180)

- These are similar to burnt clay bricks and of same size but with high compressive strength.
- These have compressive strength more than 40N/mm^2.

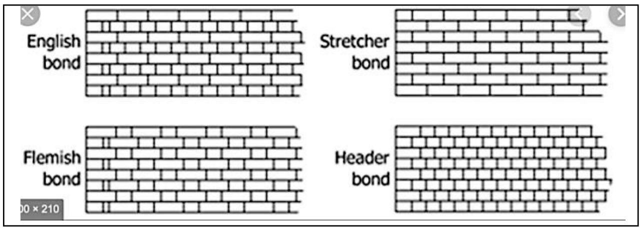
- Water absorption is less than 10 per cent after 24 hours immersion in water.
- Efflorescence is nil.
- Bulk density: should be less than 2500 kg/m^3.
- These are used for heavy duty structures such as bridges, foundations for industrial buildings, multi-storey buildings, etc.

k) Brick Masonry

- Definitions
  - Stretcher: longer face of brick is termed as stretcher.
  - Header: shorter face is called header
  - Closer: if brick is cut along the length then the portion obtained is closer.
  - Bat: if brick is cut along the width then the portion obtained is bat.
  - When the brick is cut along the length, it is called queen closer and when cut at one end by half header and half stretcher, it is known as king closer.



- Bonds
  - Stretcher bond
  - Header bond
  - English bond: strongest
  - Flemish bond: better looking



l) Test on bricks

Dimension test IS 1077	➢ Twenty whole bricks are selected at random. Blisters, loose particles of clay and small projections are removed. ➢ They are arranged upon a level surface successively, in contact with each another. (in accordance with which dimension needs to be measured) ➢ The overall length of the assembled bricks shall be measured with steel tape. ➢ Tolerance for modular brick 3800 ± 80 , 1800 ± 40 , 1800 ± 40
Compressive strength test **IS 3495 Part 1**	➢ Remove unevenness to provide two smooth and parallel faces by grinding. Immerse in water at room temperature for 24 hours. ➢ Remove the specimen and drain out surplus moisture at room temperature. Fill the frog and all voids in the bed face flush with cement mortar. ➢ Store under the damp jute bags for 24 hours followed by immersion in clean water for 3 days. Remove, and wipe out any traces of moisture. ➢ Place the specimen with flat face horizontal, and mortar filled face upwards between 2-3 plywood sheets each of 3mm thickness. ➢ Apply load axially at a uniform rate 14N/mm^2 per minute till failure occurs. The average of results shall be reported.
Water absorption test IS 3495 Part 2	➢ Dry the specimen in a ventilated oven at a temperature of 105 to 115ºC till it attains constant mass. ➢ Cool the specimen to room temperature and obtain its weight (M1) ➢ Immerse completely dried specimen in clean water at a temperature 27ºC for 24 hrs. ➢ Remove the specimen & wipe out any traces of water with damp cloth & weigh (M2) ➢ Water absorption $w = \frac{M2-MF}{MF} \times 100$ ➢ w = 20% for compressive strength up to 12.5 MPa, ➢ w = 15% for higher class (IS 1077)
Efflorescence test	➢ A shallow flat bottom dish containing sufficient distilled water to completely saturate the specimens.

<table>
<tr><td>IS 3495 Part 3</td><td colspan="4">➢ Place the end of the bricks in the dish, the depth of immersion in water being 25mm.
➢ Place the whole arrangement in a warm well ventilated room until all the water in the dish is absorbed and surplus water evaporates.
➢ When bricks appears to be dry, place a similar quantity of water in the dish and allow it to evaporate as before.
➢ Examine the bricks for efflorescence after the 2nd evaporation and report the results.
➢ Rating of efflorescence shall not be more than moderate up to 12.5 MPa, and slight for higher class (IS 1077)</td></tr>
<tr><td>Nil
no deposit</td><td>Slight
Not more than 10%</td><td>Moderate
Up to 50%</td><td>Heavy
50% or more</td><td>Serious
Heavy deposit with powdering</td></tr>
<tr><td>Warpage test
IS 3495 Part 4</td><td colspan="4">➢ Remove any dirt adhering to the surface
➢ For concave warpage: Place the flat surface along the surface, select the location that gives the greatest departure from straightness. Measure the distance using steel rule or wedge.
➢ For convex warpage: measure the distance from flat surface to the four corners of the brick and take the maximum of four measurements.</td></tr>
</table>

11. Stone

a) Testing of stones

- Durability test: (soundness) test is performed to find out the capacity of stone to resist disintegration and decomposition.
    - ♦ Smith test: fresh chip is put in water, if water becomes dirty, it contains earthly minerals
    - ♦ Brad’s test: for frost resistance
    - ♦ Acid test: to check weather resistance.
    - ♦ Crystallisation test (IS 1126)
        - Specimen is dried and weighed, then suspended in 14% sodium sulphate solution for 16-18 hrs at room temperature.
        - Then specimen is taken out kept in air for 4 hrs, then oven dried for 24 hrs then cooled atroom temperature.
        - Process is repeated 30 times and final % change of weight gives the measure of durability.
- Compressive strength test (IS 1121 Part I)
- Transverse strength test (IS 1121 Part II)
- Tensile strength test (IS 1121 Part III)
- Shear strength test (IS 1121 Part IV)
- Absorption test (IS 1124)
- Attrition test:
    - ♦ This test predicts the rate of wear of stones against the grinding action under traffic. Thereforethis test is primarily used for stones to be used in road construction.
    - ♦ Procedure:
        - About 5kg of 60 mm size broken stones are taken and put in two cylinders of **Deval’sattrition test** machine. (ϕ–20mm h–340mm). their axes are inclined at 30^o with horizontal.
        - Cylinders are rotated about horizontal axis for 5hrs at rate of 30rpm.
        - Percentage wear is found by finding the % loss of weight by, sieving away the finepowders.