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Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in

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CONTENT

1. Cement ..... 1 - 42
2. Concrete ..... 43 - 98
3. Timber ..... 99 - 142
4. Bricks ..... 143 - 174
5. Brick Masonary ..... 175 - 204
6. Aggregate ..... 205 - 218
7. Water ..... 219 - 222

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CHAPTER

1

Cement

INTRODUCTION

- Cement is a material which has cohesive and adhesive properties in the presence of water.
- Cement is a product obtained by pulverizing clinker formed by calcinating raw-materials primarily consisting of Lime (CaO), Silicate (SiO_2); Alumina (Al_2O_3) and Iron oxide (Fe_2O_3).
- It was invented by Joseph Aspdin of UK in 1824. He named it portland cement because the hardened concrete made out of the cement aggregate and water in definete proportion resembled the natural stone occurring at portland in England.

Note: Pulverize : Make into a powder by breaking up or cause to become dust
Clinker : A hard brick used as a paving stone.
Calcination : The process of heating a substance to a high temperature but below the melting or fusing point, causing loss of moisture, reduction on oxidation, and dissociation into simpler substances.

- When cement is mixed with water it forms a paste which hardens and binds aggregates (fine and coarse) together to form a hard durable mass called concrete.
- Cements used in construction industry can be classified as hydraulic and non hydraulic.
- Hydraulic cement set and harden in presence of water (Due to the chemical action between cement and water known as hydration) and results in water-resistant product which is stable. eg. Portland cement.
- Non-hydraulic cements are derived from calcination of gypsum or limestone because their products of hydration are not resistant to water; however, the addition of pozzolanic materials can render gypsum and lime cement hydraulic. Ex-Plaster of Paris.
- Cement can be manufactured either from natural cement stones or artificially by using calcareous and argillaceous materials. Examples of natural cements are Roman cement, Puzzolona cement and Medina cement and of artificial cement are Portland cement and special cements.

Note:

Argillaceous	Calcareous
• Shale and clay • Cement rock • Blast furnace slag • Marl	• Limestone • Chalk • Marine shells

- Certain clays formed during volcanic eruption, known as volcanic ash or pozzolana found near itlay have properties similar to that of portland cement.

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- Various varieties of artificial cement (exceeding 30 in number) are available in the market at present.

CHEMICAL COMPOSITION OF RAW MATERIALS

- The three basic constituents of hydraulic cements are lime, silica alumina and iron oxide.
- The relative proportions of these oxide compositions are responsible for influencing the various properties of cement.
- An increase in lime content beyond a certain value makes it difficult to combine completely with other compounds.
- Consequently, free lime will exist in the clinker and will result in an unsound cement. An increase in silica content at the expense of alumina and ferric oxide makes the cement difficult to fuse and form clinker.
- The approximate limits of chemical composition in cement are given in table.

Constituents of Portland Cement (Raw Material)

Oxide	*Function*	*Composition (%)*	*Average*
Lime, CaO	Controls strength and soundness. Its deficiency reduces strength and setting time.	60-65	63
Silica, SiO_2	Gives strength. Excess of it causes slow setting.	17-25	20
Alumina, Al_2O_3	Responsible for quick setting, if in excess it lowers the strength.	3-8	6
Iron oxide, Fe_2O_3	Gives colour and helps in fusion of different ingredients.	0.5-6	3
Magnesia, MgO	Imparts colour and hardness. If in excess it causes cracks in mortar and concrete and unsoundness.	0.5-4	2
Soda and/or potash, $Na_2O + K_2O$	These are residues, and if in excess cause efflorescence and cracking.	0.5-1	1
Sulphur trioxide, SO_3	Makes cement sound.	1-2	1.5

Note:
1. Rate of setting of cement paste is controlled by regulating the ratio $SiO_2/(Al_2O_3 + Fe_2O_3)$.
2. When development of heat of hydration is undesirable, the silica content is increased to about 21 per cent, and the alumina and iron oxide contents are limited to 6 per cent each.
3. Resistance to the action of sulphate waters is increased by raising further the silica content to 24 per cent and reducing the alumina and iron contents in 4 per cent each.
4. The variation in composition depends largely on the ratio of CaO to SiO_2 in the raw materials.
5. Alkalis accelerate the setting of cement paste.

COMPOSITION OF CEMENT CLINKER AND THEIR SETTING ACTION

- When these raw materials are put in kiln then it fuses and following four major compounds are formed and they are known as Bogue compound.

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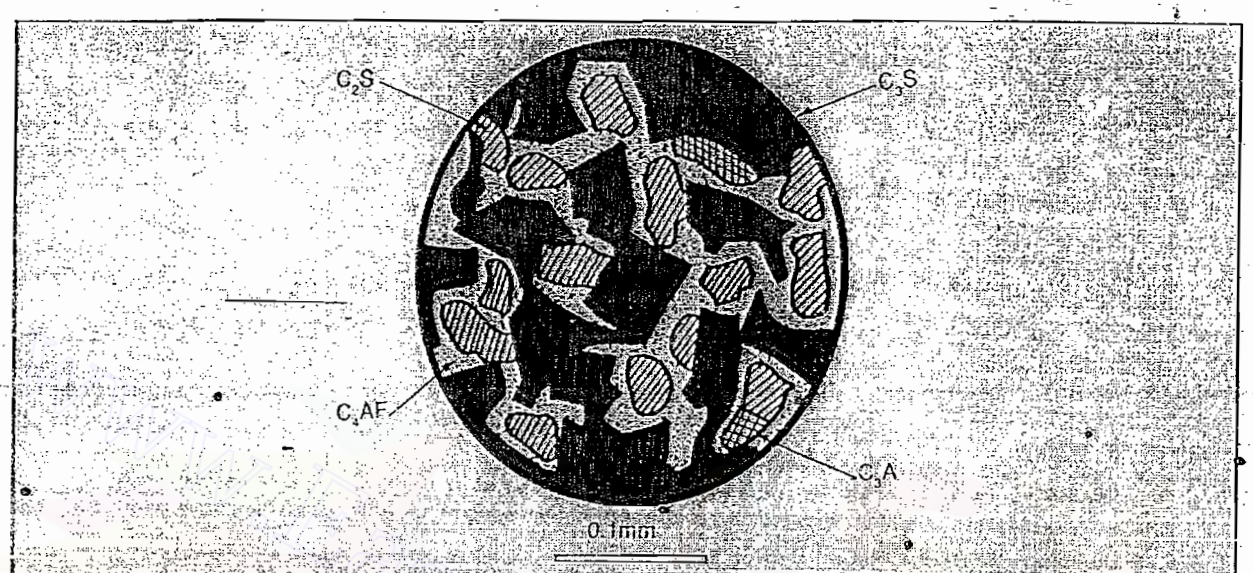
The principal mineral compounds in Portland cement	Formula	Name	Symbol
1. Tricalcium silicate	$3CaO.SiO_2$	Alite	C_3S
2. Dicalcium silicate	$2CaO.SiO_2$	Belite	C_2S
3. Tricalcium aluminate	$3CaO.Al_2O_3$	Celite	C_3A
4. Tetracalcium alumino ferrite	$4CaO.Al_2Fe_2O_3$	Felite	C_4AF



Schematic representation of the composition of portland cement

- Besides major compounds 2 minor compounds are also formed K_2O and Na_2O (Alkalies) which play an important role in the Alkali-aggregate reaction.
- The mixing of cement and water formed various complicated chemical compounds are not simultaneous.
- It is found that ordinary cement achieves about 70% of its final strength in 28 days and about 90% in 1 year.
- Properties of portland cement varies significantly with the proportions of the above four compounds, as substantial difference is observed in their individual behaviour.

1. Tricalcium Silicate C_3S– (25 – 50%)– Normally 40%

- It is considered as best cementing material and is well burnt cement.
- It enables clinker easy to grind , increases resistance to freezing and thawing.
- It hydrates rapidly generating high heat and develops an early hardness and strength.
- Rasing of C_3S content beyond the specified limits increases heat of hydration and solubility of cement in water.
- Hydrolysis of C_3S mainly responsible for 7 days strength and hardness.
- Rate of hydrolysis of C_3S and the character of gel developed are the main cause of the hardness and early strength of cement.
- Heat of hydration is 500 J/gm.

Dicalcium Silicate (C_2S) (25 – 40%) (Normally 32%)

- It hydrates and hardens slowly and takes long time to add to the strength (after a year or more)

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i.e. it is responsible for ultimate strength.

- It imparts resistance to chemical attack.
- Raising of C_2S content renders clinker harder to grind, reduces early strength, decreases resistance to freezing and thawing at early ages and decreases heat of hydration.
- At early ages, less than a month, C_2S has little influence on strength and hardness. While after one year, its contribution to the strength and hardness is proportionately almost equal to C_3S.
- Heat of hydration is 260 J/g

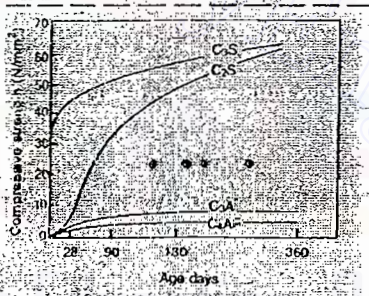
Tricalcium Aluminate (C_3A) (5 – 11%) (Normally 10.5%).

- It rapidly reacts with water and is responsible for flash set of finely grounded clinker.
- Rapidity of action is regulated by the addition of 2-3% of gypsum at the time of grinding the cement.
- It is responsible for the initial set, high heat of hydration and has greater tendency to volume changes causing cracking.
- Raising the C_3A content reduces the setting time, weakens resistance to sulphate attack and lowers the ultimate strength, heat of hydration and contraction during air hardening.
- Heat of hydration of 865 J/g.

Tetracalcium Alumino-Ferrite (C_4AF 8 –14%) (Normally 9%)

- It is responsible for flash set but generates less heat.
- It has poorest cementing value
- Raising the C_4AF content reduces the strength slightly.
- Heat of hydration 420 J/g

Note :



Contribution of Cement Compounds to Strength of Cement

HYDRATION OF CEMENT

- When water is added to cement, a chemical reaction between water and cement takes place which is known as hydration of cement.
- Heat liberated (exothermic) during this chemical reactions is known as Heat of hydration.
- It has been observed that the significant product of hydration is $(CaO\ SiO_2\ H_2O)$ which is called as Tobermorite Gel because of its structural similarity to a naturally occurring mineral Tobermorite and commonly it is reffered C-S-H Gel.

Hydration of Silicate given by equations are:

- $$2C_3S + 6H \longrightarrow C_3S_2H_3 + 3Ca(OH)_2$$
  [100] [24] [75] [49]

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- $2C_2S + 4H \longrightarrow C_3S_2H_3 + Ca(OH)_2$
  [100] [21] [99] [22]

  The number in the bracket indicates the mass of the respective compound taking part in the reaction.
- From these two above equations it can be seen that hydration of C_3S produce lesser calcium silicate hydrates (C–S–H) and more $Ca(OH)_2$ as compared to the hydration of C_2S.
- Since $Ca(OH)_2$ is not a desirable product in the concrete mass because it is soluble in water and gets leached out making the concrete porous, particularly in hydraulic structure, that's why cement with small percentage of C_3S and more C_2S is recommmended for use in hydraulic structure.
- $Ca(OH)_2$ reacts with sulphate present in soil or water to form $CaSO_4$ which further reacts with C_3A and cause deterioation of concrete, which is known as sulphate attack.
- The only advantage of $Ca(OH)_2$ is that being alkaline in nature maintain PH = 13 in concrete which resist the corrosion of reinforcement.
- **Hydration of Cement depends on following factor:**
  - (i) **Temperature at which hydration takes place:** Higher the temperature rapid is the hydration it is for this reason that in cold weather, sometimes the aggregates are heated before they are used for making concrete.
  - (ii) **Fineness of Cement:** Finner the cement rapid is the hydration because finer cements have larger surface areas. However, a very fine ground cement is susceptible to air-set and deteriorates earlier.
  - (iii) **The ingredients of cement:** The reaction can be made rapid or slow by changing the proportions of the ingredients of the cement.
- C_3S readily reacts with water, producing more heat of hydration and is responsible for early strength of Concrete.
- C_3S is the best cementing material and by increasing its percentag, the quality of cement can be improved.
- C_2S hydrates more slowly, produces less heat of hydration and is responsible for later strength of Concrete. The calcium silicate hydrate formed is dense. The hydration products of C_2S are considered better than those of C_3S.
- For most of cements, the sum of percentage of C_3S and C_2S is nearly (usually 70 to 72%).
- The reaction of pure C_3A with water is very fast and may lead to flash set. Gypsum is added at time of grinding to prevent this flash set (addition of gypsum increases the soundeness of cement). The hydrated aluminates, do not contribute anything to the strength of the paste. On the other hand, their presence is harmful to the durability of Concrete, in situations where the concrete is likely to be attacked by sulphates.
- The hydrated product due to C_4AF, also, does not contribute anything to the strength, through they are more resistant to sulphate attack.

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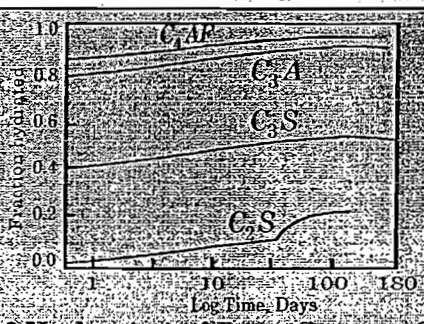

Rate of Hydration of Pure Cement Compounds

Note: • **Rate of heat evolution** of the principal compounds if equal amount of each is considered will be in following decending order: $C_3A(865J/g) > C_3S(500J/g) > C_3AF(420J/g) > C_2S(260J/g)$

• But **rate of hydration** of principal compounds in decending order will be

$$C_4AF > C_3A > C_3S > C_2S$$

Note: 1. The term setting refers to a change from a fluid to a rigid state, i.e., the stiffening of the paste. During setting cement acquires some strength. However, for pratical purpose setting is distinguished from hardening which rfefers to the gain of strength of a set cement paste.

WATER REQUIREMENT FOR HYDRATION

- About an average 23 per cent (24 percent C_3S, 21 percent C_2S) of water by weight of cement is required for complete hydration of Portland cement. This water combines chemically with the cement compounds and is known as *bound water*.
- It is further observed that about 15% of water by weight of cement is required to fill the gel pores.
- It is a general belief that a water/cement ratio less than 0.38 should not be used in concrete because for the process of hydration, the gel pores should saturated – is not valid. This is because as even if excess water is present, complete hydration of cement never takes place due to deposition of hydration products.
- As a matter of fact water/cement ratio less than 0.38 is very common for high strength concretes.
- If excess water is present, it will lead to capillary cavities.

MANUFACTURE OF CEMENT

Raw materials

- Raw materials used in the manufacture of cement are classified into two broad categories:

Argillaceous	Calcareous
Shale and clay	Limestone
Cement rock	Chalk
Blast furnace slag	Marine shells
Marl	

- From the above materials, others like lime, silica, alumina, iron oxide and small quantities of other chemicals are obtained.

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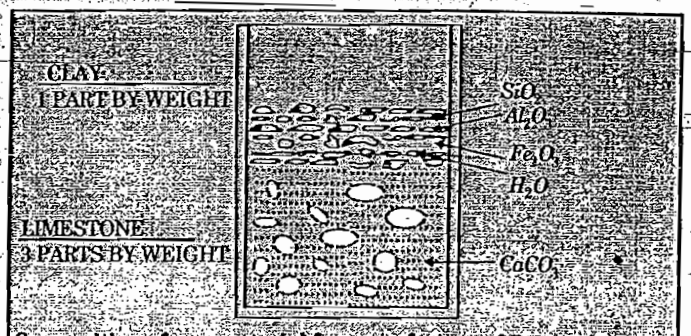
- Cement can be manufactured either by dry process or wet process.
- In these process oxides combine to form tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3S) and tetra calcium aluminoferrite (C_4AF).

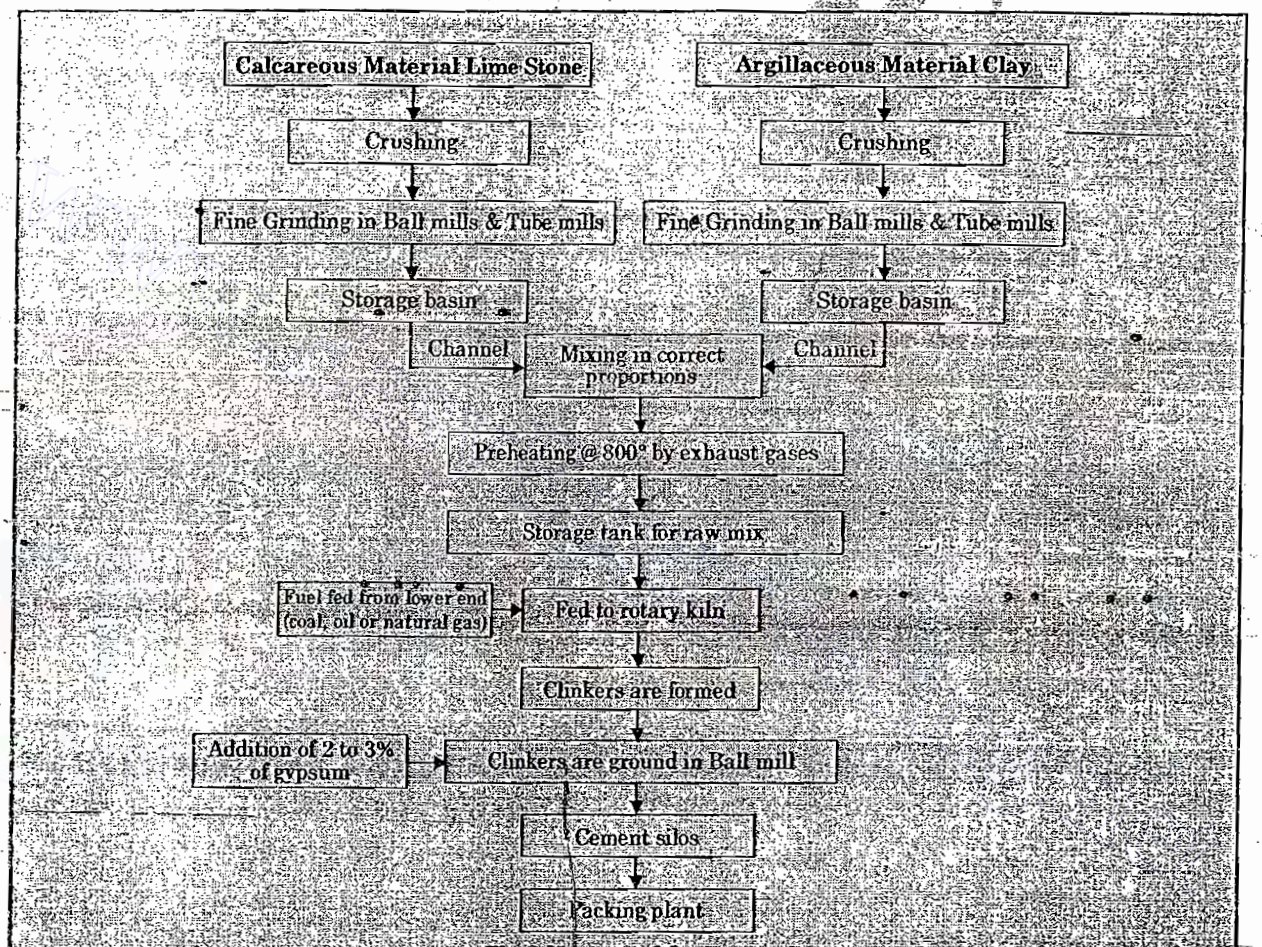


Composition of raw material for manufacture of Portland cement

Manufacturing Process

Dry Process

- Dry process is adopted when the raw materials are quite hard.
- This process is slow and the product is costly.
- Limestone and clay are ground to fine powder separately and are mixed.



Flow diagram of dry process

- Water is added to make a thick paste and cakes of this paste containing about 14 percent of moisture are dried and are charged into rotary kiln and the product obtained after calcination in rotary kiln is called as *clinker*.
- Clinker is obtained as a result of incipient fusion and sintering at a temperature of about 1400°-1500°C. Because ferric oxide has lower melting point than the other oxides, it acts as a flux.
- Aeration of cement clinker, which is commonly practised to slake free lime, also causes an absorption of moisture and carbon dioxide.
- Absorption of moisture tends to decrease the setting whereas that of carbon dioxide acelerate setting.

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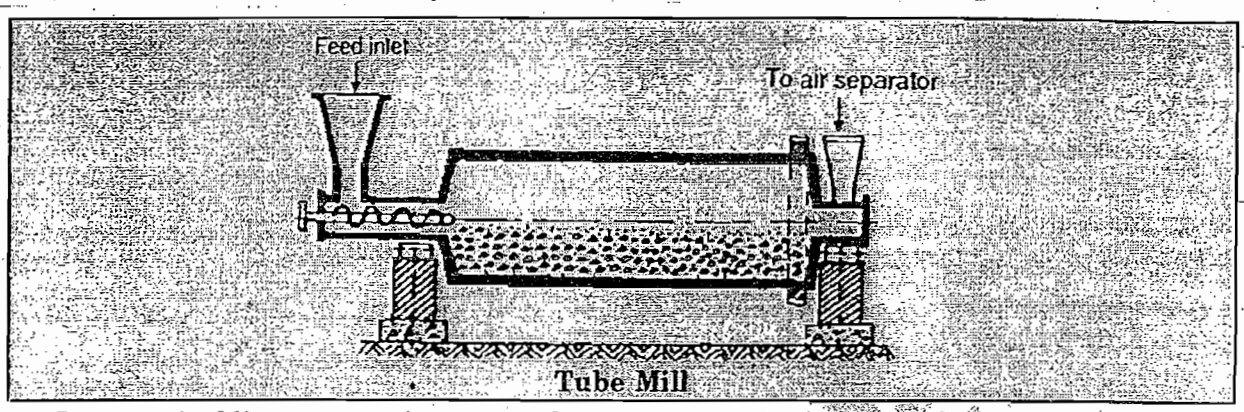
- Clinker is cooled rapidly to preserve the metastable compounds and their solid solutions — dispersion of one solid in another — which are made as the clinker is heated.
- Clinker (3 to 20mm size) is then cooled and ground in tube mills. *Where 2-3% of gypsum is added.*

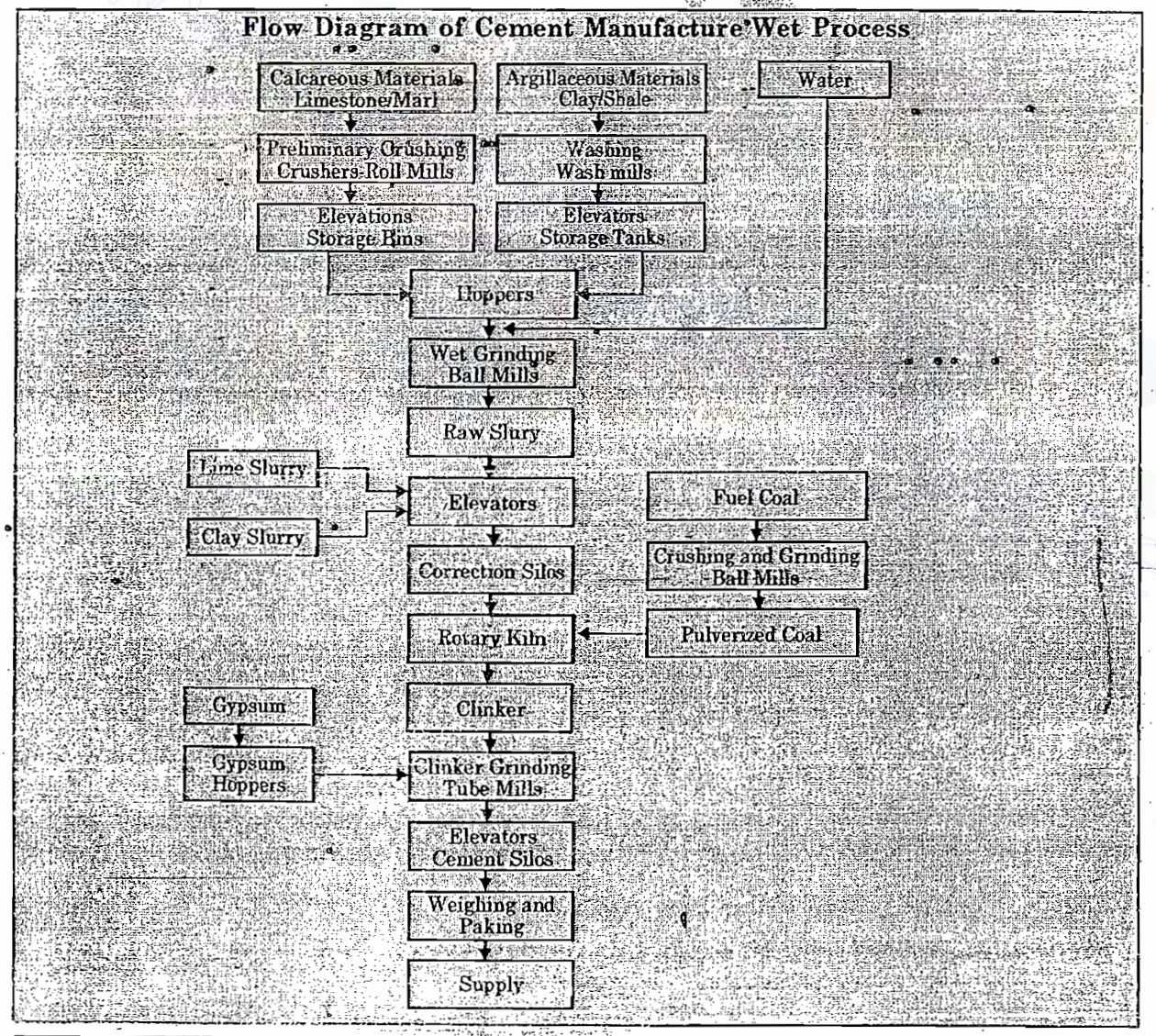


Tube Mill

- *Purpose of adding gypsum is to coat the cement particles by interfering with the process of hydration of the cement particles. This retards the setting of cement.*

Wet Process

Flow Diagram of Cement Manufacture Wet Process



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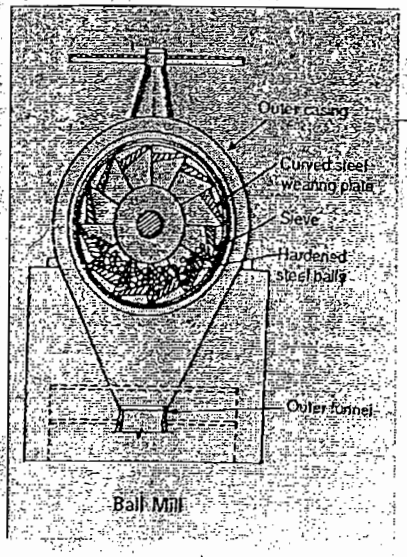

- In wet process Crushed raw materials are fed into ball mill and a little water is added.
- During operation of ball mill, the steel balls in it pulverize the raw materials which form a slurry with water.
- This slurry is passed to silos (storage tanks), where the proportioning of the compounds is adjusted to ensure desired chemical composition.
- Corrected slurry having about 40 per cent moisture content, is then fed into rotary kiln where it uses moisture and forms into lumps or nodules.
- Then it is finally burned at 1500-1600°C and nodules change to clinker at this temperature.
- Clinker is cooled and then ground in tube mills.
- *While grinding the clinker, about 3 per cent gypsum is added.*
- The cement is then stored in silos from where it is supplied.

COMPARISON OF WET AND DRY PROCESS

- Dry process is considered to be economical as compared to wet process because of less consumption of fuel in the kiln.
- Advantages of the wet process are the low cost of excavating and grinding raw materials, the accurate control of composition and homogeneity of the slurry.
- But longer kilns are required in wet process which are more costly and less responsive to a variable clinker demand than the short kilns which can be used in dry process.

TYPES OF CEMENT

PORTLAND CEMENT

- Portland Cement is the most common variety of artificial cement and it is also known as normal setting cement or ordinary cement.
- This cement is called as Portland cement because it has resemblance in its colour after setting, to a variety of sandstone which is found in abundance in Portland England.
- Ordinary portland cement has be classified as
  (a) OPC – 33 Grade. (IS : 269 – 1989)
  (b) OPC – 43 Grade. (IS : 8112 – 1989)
  (c) OPC – 53 Grade. (IS : 12669 – 1987)
- The ordinary Portland cement has been classified as 33 Grade ,43 Grade and 53 Grade.
- The number 33, 43 and 53 correspond to 28 days (characteristic) compressive strength of cement, as obtained from standard test on cement sand mortar specimens.
- These are most commonly used in general concrete construction, where there is no special durability requirement (such as exposure to sulphate attack).
- Physical requirements of all these three types of cement are almost same except for compressive strength.

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Physical requirement	Method of testing	Grade		
		33	43	53
1. Fineness (Sp surface in m^2/kg)	Blaine's air permissibility	225	225	225
2. Soundness	Le Chatelier apparatus	10mm	10mm	10mm
	Autoclave	0.8%	0.8%	0.8%
3. Setting time Initial (min)	Vicat apparatus	30	30	30
Final (max) (in mm)		600	600	600
Compressive strength (Mpa) not less than				
3 days + 1hr		16	23	27
7 days + 2hr		22	33	37
28 days + 4hr		33	43	53

- Higher strength of cement (grade 43 and 53) is achieved by.
  (i) selecting good quality of limestone as a raw material.
  (ii) Using low ash coal firing as the coal ash is detrimental to the quality of clinker
  (iii) With a better quality of limestone, having higher percentage of $CaCO_3$, the cement of higher grade (even 63 grade) can be produced.
- **Advantage of using high grade cements are:**
  (i) Saving of cement consumption for required specification of concrete.
  (ii) The reduced quantity of cement reduces the shrinkage cracks and heat of hydration.
  (iii) Development of high early strength which may facilitate the early stripping of formwork.
  (iv) Due to low percentage of alkalies, chlorides, magnesia and free lime, they offer more durable structures.
  (v) Due to high fineness, the workability of concrete increases for a given water cement ratio.
- IS:10262 has classified the OPC grade-wise from A to F based on 28 day compressive strength as follows.

Category	Strength (Mpa)
A	32.5 – 37.5
B	37.5 – 42.5
C	42.5 – 47.5
D	47.5 – 52.5
E	52.5 – 57.5
F	57.5 – 62.5

Note: According to above table 33, 43 and 53 grade of cement corresponds to categories A, C and E respectively. But, most of the 43 grade cements available in market fall in category D and that 53-grade cements in category F.

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- Cements of special characteristics for required performance in a given environment are manufactured by altering by either chemical composition of OPC , by using additives, or by using different raw materials.

Rapid hardening cement (IS: 8041)

- This cement is similar to OPC, except that it has more C_3S and less C_2S, and it is ground more finely.
- It is used in situations where a rapid development of strength is desired (e.g., when form work is to be removed early for reuse).
- This cement must not be used for mass concrete because due to large quantity of heat of hydration, the temperature inside the concrete increases, leading to formation of undesirable crack on cooling.
- RHC attains same strength in 1 day which a ordinary cement attains in 3 days with the same water cement ratio.
- It is subjected to large shrinkage and water requirement for workability is more.
- Cost of rapid hardening cement is about 10 per cent more than the ordinary cement.
- Concrete made with RHC can be safely exposed to frost, as it matures more quickly.
- It contains more C_3S and less C_2S than the OPC.

Properties

Setting time	
Initial setting time	30 minutes (minimum)
Final setting time	10 hours (maximum)
Compressive strength	
1 day	16.0 N/mm^2
3 day	27.5 N/mm^2

- It is suitable for repair of roads , bridges and in structures where load is applied in a short period of time.

Extra Rapid Hardening Portland cement (ERHC) or Ultra Rapid hardening portland cement.

- It is manufactured by intergrinding about 2% $CaCl_2$ and rapid hardening portland cement.
- While using this cement, maximum time of 10 minutes is available for mixing, transporting and placing the concrete.
- Addition of $CaCl_2$ ensure quick setting and hardening properties so that it is used for special purpose like repair works, especially in cold weather.
- It is not used in prestressed concrete.
- Rate of strength development is accelerated; a higher percentage of $CaCl_2$ causes excessive shrinkage.
- Strength gained after 1 day is 25% more and 7 days is ≈ 20% more than OPC.
- It is also known as calcium chloride cement.

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High Alumina Cement (IS: 6452)

- It's composition is very different from portland cement.
- The raw material used for its manufacture consists of bauxite (40% which is a clay with high alumina content ≥ 32%) and limes to no 40% (or chalk) 15 % iron oxide with a little % of ferric oxide and silica, magnesia, etc. ground finely at a very high temperature.
- As Since C_3A is not present, the cement has good resistance against attack by sulphate and somes dilute acids, and is particularly suitable to sea and under-water work.

Composition of a Typical High Alumina Cement

Composition	Percentage
Al_2O_3, TiO_2	43.5
Fe_2O_3, FeO, Fe_3O_4	13.1
CaO	37.5
SiO_2	3.8
MgO	0.3
SO_3	0.4
Insoluble material	1.2
Loss on ignition	0.2

- It's rapid hardening properties arises due to Al_2O_3.CaO (calcium aluminate) as the predominant compound as shown in above table in place of calcium silicate of OPC and for setting and hardening there is not free hydrated lime as in the case of OPC.
- Final setting time should not exceed 600 minutes.
- It hardens and develops strength very rapidly one day strength is 30N/mm² (which is equal to 28 days strength of OPC) and 3 day is 35 N/mm², giving out a great amount of heat.
- It should not be used in places where temperature exceeds 18°C.
- Fineness ≥ 225 m²/kg.
- Expansion ≤ 5 mm.
- It is used for refractory concrete, in industries and is used widely for pre-casting.
- It is not recommended in tropical region and not mixed with any other type of cement.

Sulphate Resisting Portland Cement (SRPC) (IS: 12330)

- It is similar to ordinary portland cement except that it contains very low C_3A content and ground finer than OPC.
- This cement is sulphate-resistant because the disintegration of harden concrete, caused by the chemical reaction of C_3A with soluble sulphate like $MgSO_4$, $CaSO_4$ and Na_2SO_4 is inhibited.
- Expansion of cement is limited to 10 mm and 0.8 per cent, when tested by Le-chatelier method and autoclave test, respectively.
- Setting times are same as that for ordinary Portland cement.
- Compressive strength of the cubes should be as follows.

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3 days ± 1 hour	10 N / mm²
7 days ± 2 hour	16 N / mm²
28 days ± 4 hour	33 N / mm²

- It should have a fineness of 400 m²/kg.
- Initial setting time ≤ 30 minutes and final setting time ≥ 600 minutes.
- It can be used as an alternative of OPC, PPC or Portland slag cement under normal conditions.
- But its use is restricted where the prevailing temperature is below 40°C and environment where chloride are present.
- It is strongly recommended for structures in sea water, coastal area and marshy lands.

Portland slag Cement (IS: 455:1989)

- It is made by intergrinding portland cement clinker, (≤ 35%) and granulated blast furnace slag (which is a waste product in the manufacture of pig iron) and gypsum.
- Slag contains oxide of lime, silica and alumina.
- Properties of these slag cements are similar to those of OPC, but they have a lower lime and higher silica and alumina content.
- With higher slag content, it has fairly high sulphate resistance, rendering it suitable for use in environments exposed to sulphate (in the soil or in ground water).
- Slag content in the cement varies between 25 to 65 per cent of the total mass of mixture.
- The Specific surface area of cement should not be less than 225 m²/kg.
- Expansion of the cement should not be more than 10 mm and 0.8 per cent when tested be Le Chatelier method and autoclave test, respectively.
- Initial and Final setting times and compressive strength requirements are same as that for 33 grade OPC.
- It can be used in all places where OPC is used, but due to its low heat of hydration it can also be used for mass concreting, e.g., dams, foundations, etc.

Super Sulphated Portland Cement (IS : 6909)

- It is manufactured by grinding together a mixture of 80 to 85% of granulated slag with 10 to 15% of calcium sulphate and about 5% of portland cement clinker to an extreme fineness.
- In this cement C_3A, which is susceptible to sulphates is limited to less than 3.5 %.
- Sulphate resisting cement can also be produced by the addition of extra iron oxide before firing; this combines with alumina which would otherwise form C_3A, instead forming C_4AF which is not affected by sulphates.
- It should be used in places with temperature is below 40°C.
- Water resistance of concretes from Super Sulphate Portland cements is higher than that of OPC because of the absence of free calcium oxide hydrate.
- It has satisfactory frost and air resistances, but it is less resistant than concrete from Portland cement.
- Due to low heat of evolution, it is useful for mass concrete work.
- It is resistant to chemical attacks particularly to sulphates.
- This cement should not be used in constructions exposed to frequent freezing-and-thawing or moistening-and-drying conditions.

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- Compressive strength should be as follows:

3 day ± 1 hour	15 N / mm^2
7 day ± 2 hour	22 N / mm^2
28 days ± 4 hour	30 N / mm^2

- It is highly resistant to sea-water, and can withstand high concentration of sulphate found in soil or ground water.
- It is also resistant to peaty acids and oils.
- It should have fineness of 400 m^2/kg.
- Expansion ≤ 5 mm.
- Initial setting time ≥ 30 minutes, and final setting time ≤ 600 minutes.
- It is highly resistant to sea-water, and can withstand high concentration of sulphate found in soil or ground water.
- It is also resistant to peaty acids and oils.

Low Heat Portland Cement (IS:12600)

- It is a portland cement with relatively lower contents of the more hydrating compounds, C_3S and C_3A and more contents of C_2S.
- This is desirable in mass concreting of gravity dam; as otherwise, the excessive heat of hydration can result in serious cracking.
- This cement possesses less compressive strength having initial setting time is about 1 hour and final setting time is about 10 hours.
- Heat of hydration should not be more than 272 and 314 k/J/kg at the end of 7 and 28 days respectively.
- Rate of development of strength is slow but the ultimate strength is same as that of OPC. To fullfill this requirement, specific surface of cement is increased to about 3200 cm^2/g.
- Expansion should not be more than 10 mm and 0.8%, by Le Chatelier method and autoclave test respectively.
- Compressive strength should be as follows.

3 day ± 1 hour	10 N / mm^2
7 day ± 2 hour	26 N / mm^2
28 day ± 4 hour	35 N / mm^2

Portland Pozzolana Cement (IS: 1489 Part I)

- Manufactured by grinding Portland cement clinker and pozzolana (usually fly ash 10 to 30% by mass of PPC) or by intimately and uniformly blending Portland cement and fine puzzolana.
- Pozzolana is a volcanic powder found in Itlay near vesuvius.
- Pozzolana (burnt clay, shale, or fly ash) has no cementing properties itself but has the property of combining with lime to produce a stable lime-pozzolana compound which has definite cementatious properties.
- Free lime present in the cement is thus removed and hence, resistance to chemical attack increases making it suitable for marine works.
- These has low rate of development of strength but ultimate strength is comparable with OPC.

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- The average compressive strength of mortar cube, (area of face 50 cm²) composed of 1:3 by mass and $\left(\frac{P}{4}\right)+3\%$ (of combined mass of cement and sand) water

  Obtained is as follows:

  (i) at 7 day ± 2 hr 22 MPa (Minimum)

  (ii) at 28 day ± 4 hr 31 MPa (Minimum)

  Where Pi is % of water to produce a paste of standard consistency.
- Initial time = 30 minutes (minimum) and final setting time = 600 minutes (maximum), respectively.
- Drying shrinkage should not be more than 0.15%
- Fineness should not be less than 300 m²/kg.
- It has low heat evolution and is used in the places of mass concrete such as dams and in places of high temperature.

Quik Setting Portland Cement

- In the manufacture of this cement, gypsum content is reduced to get the quick setting property.
- It is ground much finer than OPC.
- It sets quickly but does not harden quickly.
  Initial setting time = 5 minutes
  Final setting time = 30 minutes
- It is used when concrete is to be laid under water or in running water.

Masonry Cement (IS: 3466)

- Portland cement clinker is ground and mixed intimately with pozzolanic material (flyash or calcined clay), or non-pozzolanic (inert) materials (limestone, conglomrates, dolomite, granulated slag) and waste materials (carbonated sludge, mine tailings) and gypsum and air entraining plasticizer in suitable proportions.
- Addition of those materials gives good workability, reduces shrinkage and water vetentivity.
- This cement is used for masonary works, plaster work etc.
- This cement must not be used for concrete work.
- Physical requirements of masonry cement are as follows.

1.	Fineness: Residue on 45-micron IS Sieve, Max, Percent (by wet sieving)	15
2.	Setting Time (by Vicat Apparatus):	
(a)	Initial, Min	90 min
(b)	Final, Max	24 h
3.	Soundness:	
(a)	Le-Chatelier expansion, Max	10 mm
(b)	Autoclave expansion, Max	1 per cent
4.	Compressive Strength: Average strength of not less than 3 mortar cubes of 50 mm size, composed of 1 part masonry cement and 3 parts standard sand by volume, Min	
	7 days	2.5 MPa
	28 days	5 MPa

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5. Air Content: Air content of mortar composed of 1 part masonry cement 6 per cent and 3 parts standard sand by volume, Min — 6 per cent
6. Water Retention: Flow after suction of mortar composed of 1 part 60 per cent of masonry cement and 3 parts standard sand by volume, Min — Original flow

White and Coloured Portland Cement (IS: 8042)

- Manufactured from pure white chalk and china clay free from iron oxide.
- Greyish colour of cement is due to iron oxide, so the iron oxide is reduced and limited below 1 per cent.
- Coloured cements are made by adding 5 to 10 per cent colouring pigments before grinding.
- Such cements have same properties as that of OPC and are non-staining because of low amount of soluble alkalis.
- Sodium alumino ferrite (cryolite) Na_3AlF_6 is added during burning which acts as a catalyst in place of iron oxide.
- Hunter scale or ISI scale is used to measured the whiteness of white cement.
- Loss on ignition of white cement is nil.
- Compressive and transverse strength of this cement is 90 per cent of that of 33 grade OPC.
- Colouring pigment are as follows:
  (i) Chromium oxides gives green colour.
  (ii) Cobalt impars blue colour.
  (iii) Manganese dioxide imparts black or brown.
  (iv) Iron oxide gives brown colour.
- These are used for making terrazzo flooring, face plaster of walls (stucco), ornamental works, and casting stones.

Air Entraining Cement:

- It is made off vinsol resin or vegetable fats and oils and fatty acids are ground with ordinary cement. or
- It is manufactured by mixing a small amount (≈ 0.1%) by weight of an air entraining agent with OPC clinker at the time of grinding.
- These air entraining agents are:
  (a) Alkali salt of wood resins.
  (b) Calcium salt of glues and other protein obtained in the treatment of animal hides.
  (c) Calcium lignosulphate derived from the sulphate process in paper making.
  (d) Synthetic detergents of the alkayl–aryl sulphonate type.
- These materials have the property to entrain air in the form of fine tiny air bubbles.
- Hence Air entraining cements are used for the same purposes as that of OPC.

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- Air entrainment improves workability and w/c ratio can be reduced which in turn reduces shrinkage, etc.
- Minute voids are formed while setting of cement which increases resistance against freezing and scaling action of salts.

Water Repellent Cement (IS : 8043) or Hydrophobic cement.

- It is manufactured by grinding OPC clinker with 0.1 to 0.4% of oleic acid, stearic acid or pentachlorophenol.
- This addition forms water repellent film around each particular of cement and therefore transporation and storage of this cement is not affected by the moisture content of atmosphere.
- When concrete is being prepared, hydrophobic admixtures plasticize the mix and contribute to the formation of uniformly distributed fine pores in concrete as it hardens and thus enhance its frost resistance. Hydrophobic cement also features greater water resistance and water impermeability.
- Specific surface of hydrophobic cement should not be less than 350 m^2/kg.
- Average compressive strength should not be less than

3 day ± 1 hour	15.69 N/mm^2
7 day ± 2 hour	21.57 N/mm^2
28 day ± 4 hour	30.40 N/mm^2

- Weak points of hydrophobic cement are its small strength gain during the initial period because of the hydrophobic films on cement grains which prevent the interaction with water, but its 28-day strength is equal to OPC.
- It is most suitable for basements and for making water tight concrete.

Water Proof Cement

- It is manufactured by adding water-proofing agent like metal stearates (metal be Ca, Al---) or non-sponifiable oil to ordinary portland cement during grinding.
- Concrete made with this cement is more impermeable.
- It is used in water retaining structures like tanks, reservoirs, retaining walls, swimming pools, bridge piers, etc.

Expanding Cement

- Manufactured by adding an expanding medium like sulpho-aluminate and a stabilising agent to the ordinary cement.
- It is used to neutralize the shrinkage of concrete to eliminate cracks.
- Concrete made with ordinary portland cement shrink while setting due to loss of free water whereas the volume of expanding cement increase on hardening hence shrinkage and expansion of volume are adjusted.
- Curing must be carefully controlled since expansion occurs only as long as concrete is moist.
- One type of expansive cement is known as shrinkage compensating cement. This cement when used in concrete , with restrained expansion induces compressive stress which more or less offset the tensile stress induced by shrinkage.
- Another type is known as self stressing cement. This induce significant compressive stress after compensating the shrinkage stress, also gives some sort of prestressing effect in the tensile zone

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of a flexural member.

- A popular non-shrinking grout developed by Associated Cement Co.Ltd. is known as **shrinkomp.**

Oil Well Cement

- This cement is specially manufactured for the use in oil well to fill the space between the steel casing and the wall of the well.
- It is commonly used in the form of cement slurry for cementing oil-wells, under extreme conditions of temperature and pressure.
- The oil-well cement has a high resistance to sulphate attack.

Natural Cement

- It is obtained by burning and crushing the stones containing clay (20 to 40%), carbonate of lime and some amount of carbonate of magnesia.
- It is brown in colour and its best variety is known as the roman cement.
- It resembles very closely eminent hydraulic lime.
- It sets very quickly after addition of water.
- It is not so strong as artificial cement and hence it has limited use in practice.

Acid-Resistant Cement

- An acid-resistant cement is composed of the following:
  (a) acid-resistant aggregates such as quartz, quartizites.
  (b) Aqueous solution of sodium silicate or soluble glass.
  (c) Additive such as sodium fluosilicate Na_2SiF_6.
- Addition of additive sodium fluosilicate (Na_2SiF_6) accelerates the hardening process of soluble glass and it also increases the resistance of cement to acid and water.
- The binding material of this cement is soluble glass which is a water solution of sodium silicate, $Na_2O.nSiO_2$ or potassium silicate, $K_2O.nSiO_2$ where n is the glass modulus varies from 2.5 to 3.
- Glass modulus indicates the ratio of the number of silica molecules to that of alkali oxide molecules.
- Addition of 0.5% of linseed oil or 2% of ceresit, its resistance to the water is increased and it is then known as the acid and water resistant cement.

TESTING OF CEMENT

- Exhaustive tests are carried out in laboratory to decide precisely the quality of cement.
- In order to make a representative sample, it is desirable to collect in nearly equal portions as follows.
  (i) **When cement is loose :** It should be taken from at least 12 points from heap or heaps of cement.
  (ii) **When cement is in bags :** It should be taken from at least 12 different bags or packages.
- Quantity of cement so collected is intimately mixed and the final sample of cement weighing at least 50N is prepared. It is then stored in airtight container till the tests are started.
- Following are the purposes of testing of cement (BIS:4031/1968)
  (i) Determine the physical and chemical properties of cements;
  (ii) Regulate the various stages in the manufacturing process as a slight difference in the

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process of manufacture of cement may cause a great difference in the quality of cement.

(iii) Understand the behaviour of cement after its use on the works.

- Following are standard test of cement.

Testing of cement

- **Field Test**
  - (i) Colour
  - (ii) Physical properties
  - (iii) Presence of lumps
  - (iv) Strength.
- **Lab Test**
  - **Physical Test**
    - (1) Fineness Test
    - (2) Consistency Test
    - (3) Initial and Final setting time
    - (4) Soundness Test
    - (5) Determination of strength
    - (6) Heat of Hydration
    - (7) Specific Gravity
  - **Chemical Test**
    - (i) Loss on ignition
    - (ii) Chemical composition test

FIELD TESTS FOR CEMENTS

- Following four field tests may be carried out to ascertain roughly the quality of cement:

(i) **Colour:** Colour of cement should be uniform. i.e. grey colour with a light greenish shade.

(ii) **Physical Properties:** Cement should feel smooth when touched or rubbed in between fingers.

- If it is felt rough, it indicates adulteration with sand.
- If hand is inserted in a bag or heap of cement, it should feel cool and not warm
- If a small quantity of cement is thrown in a bucket of water, it should sink and should not float on the surface.
- A thin paste of cement with water should feel sticky between the fingers.
- If the cement contains too much of pounded clay and silt as an adulterant, the paste will give an earthy smell.

(iii) **Presence of lumps :** Cement should be free from any hard lumps. Such lumps are formed by the absorption of moisture from the atmosphere.

- Any bag of cement containing such lumps should be rejected.

(iv) **Strength:** Strength of cement can be roughly ascertained in the following ways.

(a) Briquettes with a lean or weak mortar are made. Size of briquette may be about 75mm × 25mm × 12mm. The proportion of cement and sand may be 1 : 6. The briquettes are immersed in water for a period of 3 days. If cement is of sound quality, such briquettes will not be broken easily and it will be difficult to convert them into powder form.

(b) A block of cement 25mm × 25mm and 200 mm long is prepared and it is immersed for 7 days in water. It is then placed on supports 150mm apart and it is loaded with a weight of 340 N. The block should not show signs of failure.

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(c) A thick faster of cement with water is made on a piece of thick glass and it is kept under water for 24 hours. It should set and not crack.

PHYSICAL LAB TEST

1. Fineness Test

- Degree of fineness of cement is the measure of the mean size of the grain in it.
- There are three methods of testing of fineness of cement.
  (a) Sieve method – using 90 micron (9.No.) Sieve
  (b) Air permeability method – Nurse and Blaine's method
  (c) Sedimentation method – Wanger turbidimeter method
- Sieve method measures grain size where as air permeability method and sedimentation measures surface area.
- Since cement grains are finer than 90 micron, the sieve analysis method does not represent true mean size of cement grains. Also, the tiny cement grains tend to conglomerate into lumps resulting in distortion in the final grain size distribution curves.
- Due to these demerits, fineness is generally expressed in terms of specific area, which is the total surface area of the particles in unit weight of material.

Conditions affecting Fineness

- Chemical composition and the degree of calcination influence the hardness of the clinker and hence fineness to which the cement is ground.
- Clinker with high iron or silica content or hard-burned is found to be hard and difficult to grind.
- Time of grinding and type of pulverizing machine also affects the fineness of cement.
- It has been observed that cement becomes finer with age provided that it does not absorb too much moisture. This is supposedly due to the breaking of the coarser grains resulting from the hydration of the embedded lime particles.

Importance

- With increase in fineness , the early development of strength is enhanced but the ultimate strength is not affected.
- Setting time decreases with increase in the fineness
- Increase in fineness of cement , increases the cohesiveness of the concrete mix and thus reduces bleeding, while compacting with vibrators.
- Finer cement leads to a stronger reaction with alkali (reactive aggregate) and increases the chances of shrinkage and cracking of the cement paste.
- If the cement is ground beyond a certain limit, its cementative properties are affected due to the prehydration by atmospheric moisture.

(a) Sieve Method

- 100 gm of cement sample is taken and air-set lumps in the sample are broken with finger.
- Sample is placed on a 90 micron sieve and continuously sieved for 15 minutes. The residue should not exceed the limits specified below:

Type of cement	Percentage of residue by weight	Specific surface (m^2 / kg) not less than
1. Ordinary Portland Cement (OPC)	10	225
2. Rapid Hardening Cement (RHC)	5	325
3. Portland Pozolana Cement(PPC)	5	300

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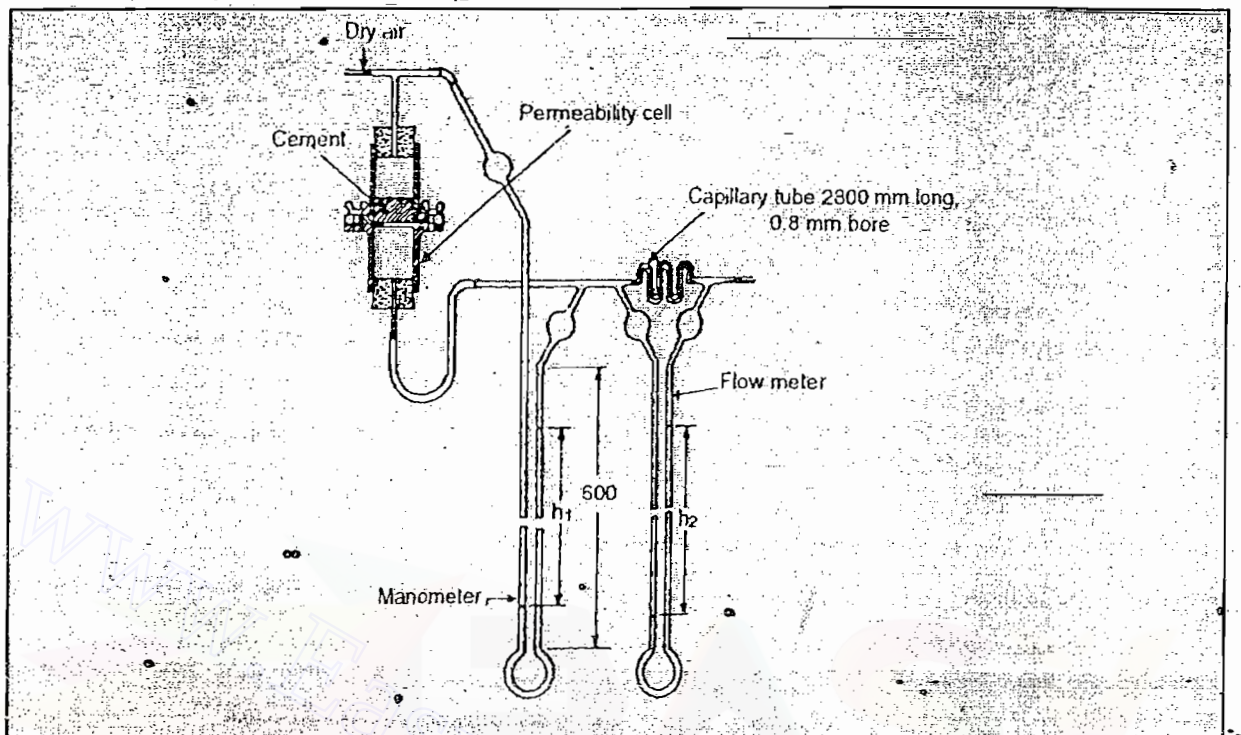
(b) Air Permeability Method:

- Fineness of cement is determined by Nurse and Blaine's method using an appratus developed by Lea and Nurse.



Premeability Appartus

Apparatus

- Consists of a permeability test cell—where cement is placed and air pressure is applied, flow-meter—to determine the quantity of air passing per second through its capillary tube per unit difference of pressure, and manometer—to measure the air pressure.

Procedure

(i) A cement sample of 20 mm height is placed on a perforated plate (40 micron perforations) and air pressure is applied and manometer connected to the top of the permeability cell and the air is turned on.

(ii) Lower end of the permeability cell is then slowly connected to the other end of the manometer.

(iii) Rate of flow is so adjusted that the flowmeter shows a pressure difference (h_2) of 30-50 cm. and reading (h_1) in the manometer is recorded.

(iv) The process is repeated till the ratio h_1/h_2 is constant and specific surface is given by the expression

$$S = \frac{14}{d(1-\psi)}\sqrt{\frac{A\psi^2}{KL}}\sqrt{\frac{h_1}{h_2}}$$

where,

L = thickness of cement layer

A = area of cement layer

d = density of cement

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ψ = porosity of cement (0.475)

h_1 = manometer reading

h_2 = flowmeter reading

K is the flowmeter constant and is obtained by

$$Q = \frac{Kh_2d_1}{\mu}$$

where,

μ = viscosity of air

d_1 = density of kerosene

$$Q = \text{quantity of air passed per second} = \frac{V}{t}\frac{P-p}{P}$$

where,

P = atmospheric pressure

p = vapour pressure of water at room temperature

Minimum Specific Surfaces of Cements

Type of Cement		Specific surface not less than cm^2/g
Ordinary Portland Cement	(OPC)	2250
Rapid Hardening Cement	(RHC)	3250
Low Heat Cement	(LHC)	3250
Portland Pozzolana Cement	(PPC)	3000
High Alumina Cement	(HAC)	2250
Super Sulphate Cement	(SSC)	4000

Wagner Turbidimeter

- L.A. Wagner developed a turbidimeter to measure the surface area of 1 gm of cement.
- In this test cement is dispersed uniformly in a rectangular glass tank filled with kerosene.
- Then, parallel light rays are passed through the solution which strike the sensitivity plate of a photoelectric cell.
- Turbidity of the solution at a given instant is measured by taking readings of the current generated by the cell.
- Recording the readings at regular intervals while the particles are falling in the solution, it is possible to secure information regarding the grading in surface area and in size of particle.

2. Consistency Test

- This test is to estimate the quantity of mixing water to form a paste of normal consistency.
- Normal consistency is defined as that percentage water requirement of the cement paste, the viscosity of which will be such that the Vicat's plunger penetrates up to a point 5 to 7mm from the bottom of the Vicat's mould.

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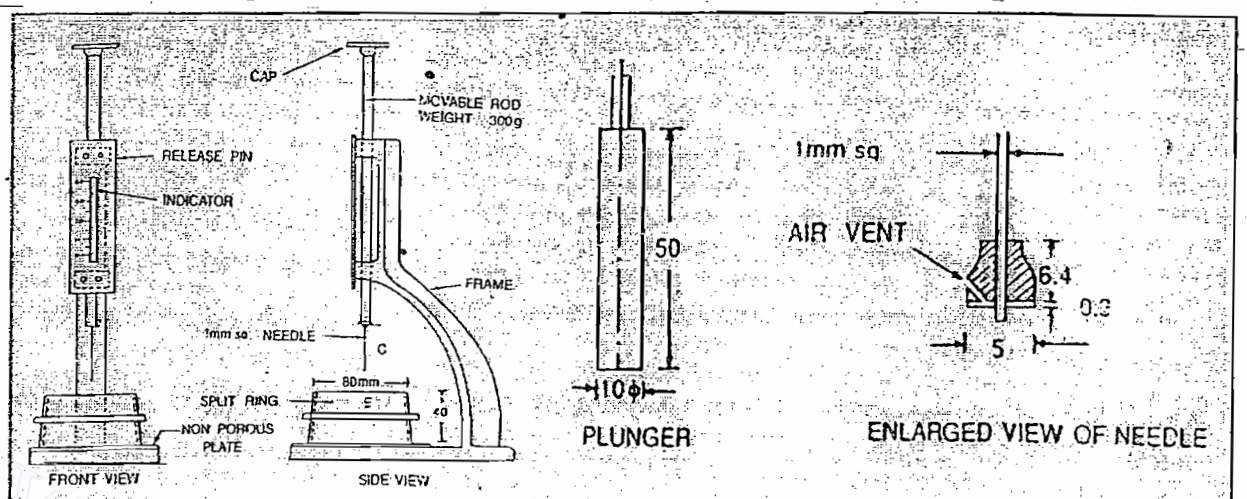
Why it is done?

- The water requirement for various tests for various tests of cement depends on the normal consistency of the cement, which itself depends upon the compound composition and fineness of the cement.



VICATS Appratus

Vicats Apparatus

- It consists of a frame to which is attached a movable rod weighing 300 gm and having diameter and length as 10 mm and 50 mm respectively.
- An indicator is attached to the movable rod, which indicator moves on a vertical scale and it gives the penetration.
- Vicat mould is in the form of a cylinder and it can be split into two halves.
- Vicat mould is placed on a non porous plate.
- There are three attachments, square needle, plunger and needle with annular collar.

Attachment	Use
10 mm ϕ Plunger	Consistency test
1 mm² needle	Initial setting time
5 mm ϕ annular colar	final setting time

Procedure

- A square needle 10 mm x 10 mm attached to the plunger is then lowered gently over the cement paste surface and is released quickly.
  Plunger pierces the cement paste and reading on the attached scale is recorded.
- When the reading is 5-7 mm from the bottom of the mould, the amount of water added is considered to be correct percentage of water for normal consistency.

3. Setting Time

- When water is added to cement and mixed properly, the chemical reaction soon starts and the cement paste remains plastic for a short period. During this period it is possible to remix the paste and this period is called initial setting time.

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- It is assumed that no hardening will start in this period. As the time passes, the reaction is continued and cement begins to harding and time elapse at the times of mixing water to hardened is known as final setting time.

(a) Initial setting time test.

Procedure

- The cement weighing 300 gm is taken and make a cement paste of consistency 0.85 P.
- The cement paste is filled in the vicat mould.
- Square needle 1 × 1 mm is attached to the moving rod of the vicat apparatus.
- The needle is quickly released and it is allowed to penetrate the cement paste.
- When the needle penetrates only 5 to 7mm from the bottom, it shows that test is completed.
- Initial setting time should not be less than 30 minutes for OPC and 1hr. for low heat cement.

(b) Final setting time test

Procedure

- The cement paste is prepared as above in (a) and it is filled in the vicat mould.
- The needle with annular collar is attached inplace of square needle.
- The needle is gently released. The time at which the needle makes an impression on test block and the collar fails to do so is noted.
- The final setting time is the difference b/w the time at which water was added to cement and the time as recorded (noted).
- The final setting time ≯ 10 hours.

Why Initial and Final Setting Test is done?

Initial setting time test in done because:

- Concrete once placed should not be disturbed till the initial setting has taken place.
- There must be sufficient time for placing of second batch otherwise this may disturb the first batch of concreting.
- The transportation of concrete from the place where concrete is prepared to the placing of concrete required some finite time for that also initial setting time test is required.
- Final setting time test is done because the concrete should achieve the desired strength as early as possible so that the shuttering can be removed and reused.

4. Soundness Test

- Purpose of this test is to detect the change in volume of cement after setting.
- Soundness of cement is tested by Le-Chatelier method or by autoclave method.
- Soundness of cement can be ensured by limiting the quantities of free lime and magnesia which slake slowly causing change in volume of cement (known as unsound).
- It is a very important test to assure the quality of cement since an unsound cement produces cracks, distortion and disintegration, ultimately leading to failure.

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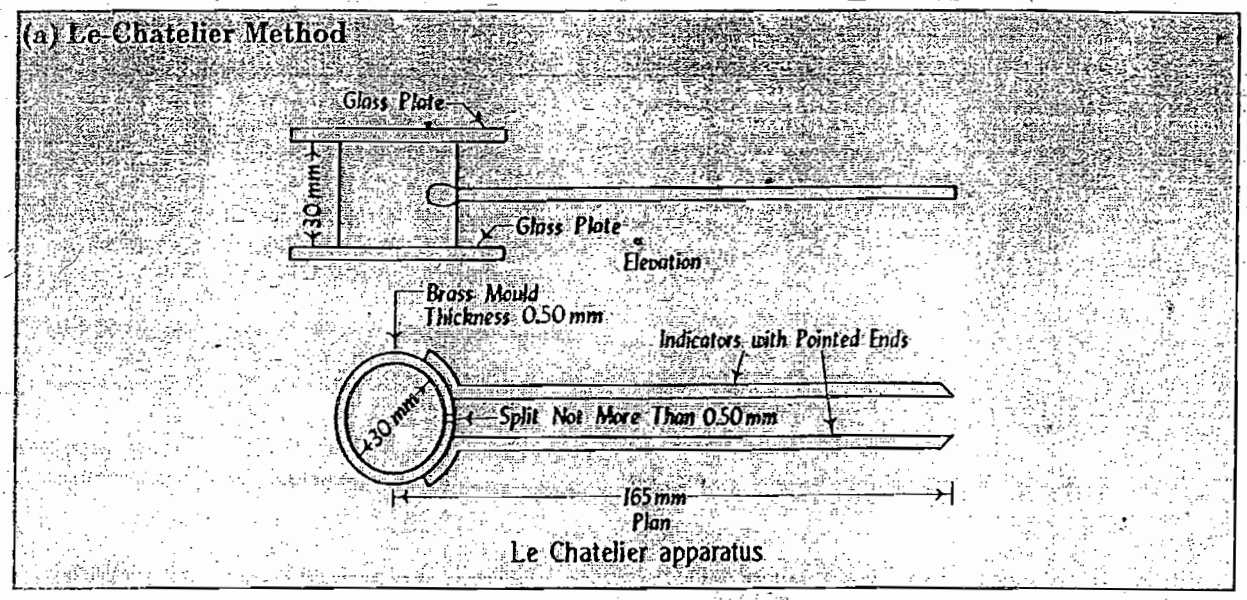
(a) Le-Chatelier Method



Le Chatelier apparatus

Procedure

1. Cement paste is prepared with 100 gm of cement sample + 0.78P. (P = water required to give a paste of standard consistency)
2. A mould of 30 mm dia and height 30mm is placed on glass plate and it is filled by cement paste.
3. Now mould is covered with a glass sheet and a small weight is placed on the covering glass sheet.
4. Mould is then submerged in the water at temperature of 27°-32°C. After 24 hours, the mould is taken out and the distance separating the indicator points is measured.
5. Mould is again submerged in water in such a way that boiling point of water is reached in 25 to 30 minutes and water is now boiled for 3 hours.
6. Mould is removed from water and is cooled down. The distance between the indicator points is measured again.
7. Difference between the two measurements represents the unsoundness of cement.
8. For OPC, RHC, LHC and PPC it is limited to 10mm, whereas for High Alumina Cement and Super Sulphate Cement it should not exceed 5mm.

- The Le-chatelier's method detect unsoundness due to free lime only.
- The excess of magnesia and calcium sulphate is not detected.

(b) Autoclave test

- In India, the occurance of low magnesia lime stone is limited so Indian standard. Specification recommended that cement having a magnesia content > 3% be tested for soundness by autoclave test.
- This test is sensitive to both free magnesia and free lime.

Procedure

- A specimen in mould of 25×25mm × 282mm internal length is placed.
- The specimen is removed from the mould and placed in autoclave at room temperature.
- Now the steam pressure inside the autoclave is raised at such a state as to bring the gauge pressure of the steam to 2.1 ± 0.1 N/mm^2 is 60 to 75 minutes from the time heat is switched on.
- This pressure is allowed to maintained for 3 hrs.
- The autoclave is cooled and length of the specimen is measured again.
- The difference in length of test specimen before and after autoclaving is calculated to the nearest 0.01% of the effective length and reported as autoclave expansion of the cement.
- For sound cement the expansion should not exceed 0.8%.

I.E.S MASTER
Institute for Engineers
IES/GATE/PSUs
Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
Phone: 011-41013465, 7838813406, 9711853908

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Conditions Affecting Soundness

- Main reason of unsoundness in portland cement is the hydration of the uncombined lime encased with in the cement particles.
- Therefore freshly grounded cement is allowed to aerate for two to three weeks, allowing the lime to hydrate, to overcome unsoundness.
- Sometimes excess gypsum added to cement to retard setting time can cause unsoundness by formation of calcium sulphoaluminates. Therefore, very strict control is kept over the quantity of gypsum to be added to the clinker, i.e. 2.5 to 3%.

Note: Principal involved in testing of soundness of cement is to artificially accelerate the process of slaking of calcium.

5. Strength Test

- Cement hydrates when water is added to it and cohesion and solidity is experienced. It binds together the aggregates by adhesion.
- The strength of mortar and concrete depends upon the type and nature of cement.
- Therefore, it should develop atleast a minimum specified strength if it is to be used in structures.
- Cement is tested for compressive and tensile strengths.

Compressive Strength

- It is fundamental and basic information required for the concrete mix design.
- By this test, the quality and the quantity of concrete can be controlled and the degree of adulteration can be checked

Procedure

1. A mixture of cement (185 gm) is mixed with standard sand 55 gm (Ennore sand) proportion of 1:3 by weight is mixed for one minute and then water $\left(\frac{p}{4}+3\right)$ % is added until the mixture is of uniform colour, where P = percentage of water required to produce a past of standard consistency.
2. Temperature of water and test room should be 27°C ± 2°C.
3. Material for each specimen cube is mixed separately.
4. Mould is filled completely with the cement paste and is placed on the vibration table. Vibrations are imparted for about 2 minutes at a speed of 12000±400 per minute.
5. Three specimen cubes are prepared of size 70.6 mm (having face area of about 5000 m^2).

Note: Large size specimen cubes can not be made since cement shrinks and cracks may develop.

6. Cubes are then removed from the moulds and submerged in clean fresh water and are taken out just prior to testing in a compression testing machine.
7. Load is applied starting from zero at a rate of 35 N/sq mm/minute.
8. Compressive strength is calculated from the crushing load divided by the average area over which the load is applied. The result is expressed in N/mm^2.
9. Compressive strength is taken to be the average of the results of the three cubes.

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Minimum Specified Strength in N/mm²

Type/Days	1 day	3 days	7 days	28 days
Ordinary Portland Cement (33 grade)	—	16.0	22.0	33.0
Portland Pozzolona cement	—	16.0	22.0	33.0
Low heat Portland cement	—	10.0	16.0	35.0
Rapid hardening cement	16.0	27.5	—	—
High alumina cement	30.0	35.0	—	—

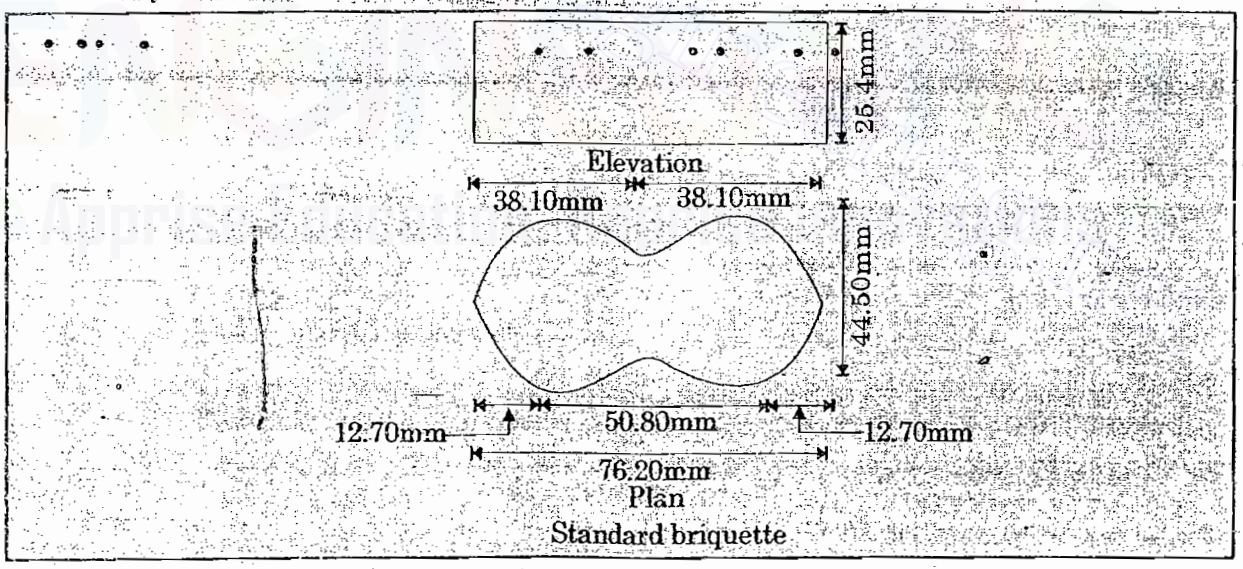
Tensile Strength

- Tensile strength is determined by Briquette test method.
- This test was formerly used to have an indirect indication of compressive strength of cement.
- It is approximately 10-15% of compressive strength.
- This method at present is generally used for RHC.
- Tensile strength test can be performed more conviniently and provide quicker indications of defects in cement in comparison to compressive strength test.

Briquette Method

Procedure

1. Mixture of cement and sand is gauged in the proportion of 1:3 by weight.
2. Percentage of water to be used is [(P/5) + 2.5]%, where P = percentage of water required to produce a paste of standard consistency.
3. Mix is filled in the briquette moulds and surface of would be finished with the blade of a trowel.
4. Now they are leaved for 24 hours at a temperature of 27 ± 2°C having 90% atmospheric humidity.



Standard briquette

5. Briquettes are then kept in clean fresh water and are taken out before testing. 6 briquettes are tested and the average tensile strength is calculated.
6. Load is applied steadily and uniformly, starting from zero and increasing at the rate of 0.7 N/mm² 12 seconds.

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7. Ordinary Portland cement should have a tensile strength of not less than 2.0 N/mm² after 3 days and not less than 2.5 N/mm² after 7days.

Note:
- Strength increases when the loading rate is increased from that specified.
- In tension test of cement the load on the briquettes should be applied centrally. Since briquettes become brittle with age, the effect of slight eccentricity or any torsional strain is pronounced in long-time tests.

Condition affecting strength

- Cement is very strong at early ages if a high lime or high alumina content is there.
- Gypsum and Plaster of Paris in small percentages also tend to increase the strength slightly, but when present in quantities larger then 3 per cent, these substances provide variable effects.
- Strength of cement is greatly influenced by the degree of burning, the fineness of grinding, and the aeration it receives subsequent to final grinding. An underburnt cement is likely to be deficient in strength.

6. Heat of Hydration

- During hydration of cement heat is evolved and it is dependent on the relative quantities of clinker on the relative quantities of clinker compounds.
- Heat of hydration is important in two cases.
  (a) **Mass concrete :** As the thermal Conductivity of concrete is low, the heat liberated in the interior of large mass does not come to the surface, while exterion surface loses the heat to atmosphere fairly quickly. This causes a temperature difference with in the concrete mass causing differential movement in the concrete which is restrained and resulting unnecessary stress and cracks.
  (b) **Concreting during winter :** During winter heat of hydration prevents the capillary moisture in the concrete from freezing which is advantageous.

Note: For mass concreting, during summer low heat portland cement is useful, whereas during winter Rapid hardening portland cement, which produces more heat is useful.

Proceduce

- Apparatus used to determine the heat of hydration of cement is known as calorimeter
- 60 g of cement and 24 ml of distilled water are mixed for 4 minutes at temperature 15–25°C.
- Three specimen glass vials 100 × 20 mm are filled with this mixture, corked and sealed with wax.
- Vials are then stored with the mixture in a vertical position at 27 ± 2° C
- Heat of hydration is obtained by subtracting the respective heat of solution of unhyrated cement calculated nearest to 0.1 calorie.
- For determining the heat of solution of unhydrated cement, weigh a sample of about 3 g. At the same time, weigh out 7.0 g of cement for the loss on ignition.

Heat of solution (Cal/g) of unhydrated cement

$$= \frac{\text{Heat capacity} \times \text{corrected temperature rise}}{\text{Weight of sample for ignition loss}} - 0.2(\varphi_0 - \varphi)$$

Where, 0.2 = Specific heat of unhydrated cement φ_0 = Room temp in °C

φ = Final temperature of the calorimeter.

I.E.S MASTER
Institute for Engineers
IES/GATE/PSUs
Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
Phone: 011-41013406, 7838813406, 9711853908

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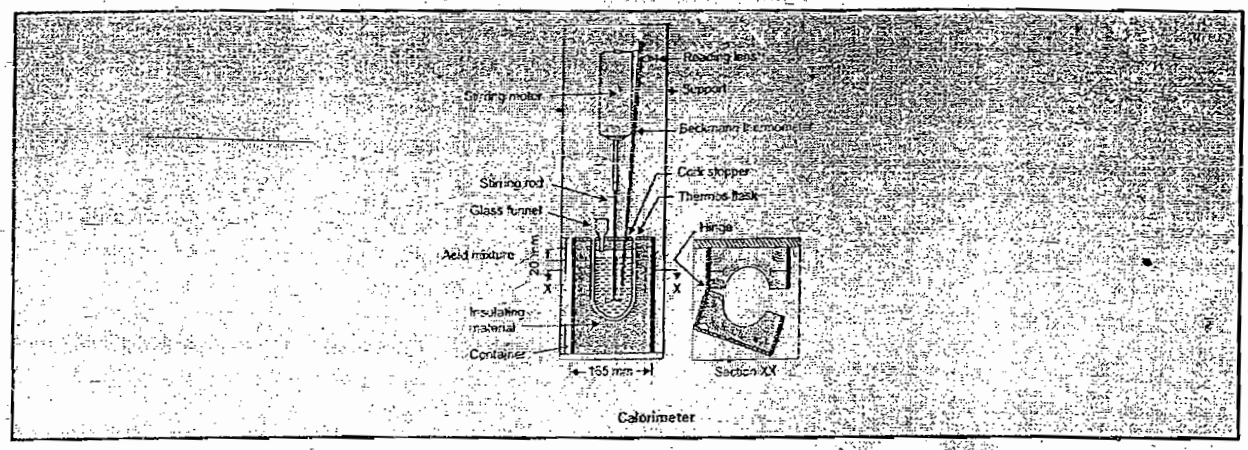
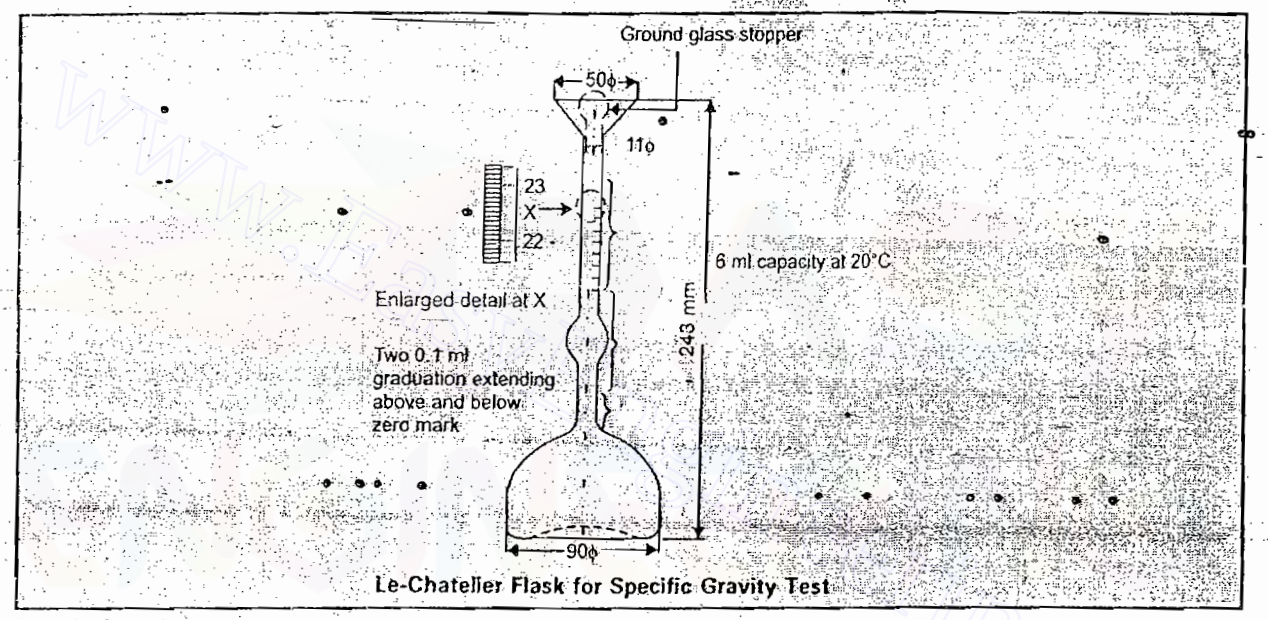


Calorimeter

7. Specific Gravity test

- Specific gravity of hydraulic cements is obtained by using Le-chatelier's flask.
- Generally specific gravity of OPC = 3.15



Le-Chatelier Flask for Specific Gravity Test

Procedure

- Flask is filled with either kerosene free of water, or naphtha having a specific gravity not less than 0.73 to a point on the stem between zero and 1-ml mark. Then flask is immersed in a constant temperature water bath and the reading is recorded.
- A weighed quantity of cement (about 64 g of Portland cement) is then introduced in small amounts at the same temperature as that of the liquid.
- After introducing all the cement, the stopper is placed in the flask and the flask rolled in an inclined position, or gently whirled in a horizontal circle, so as to free the cement from air until no further air bubbles rise to the surface of the liquid.
- Flask is again immersed in the water-bath and the final reading is recorded.
- Difference between the first and the final reading represents the volume of liquid displaced by the weight of the cement used in the test.

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- Specific gravity = $\frac{\text{wt. of cement in gms}}{\text{wt. of displaced vol of liquid in ml}}$

Conditions affecting specific Gravity

- Due to Long seasoning unadulterated cement has low specific gravity because freshly ground cement when exposed to air rapidly absorbs moisture and carbon dioxide.
- Cement with high contents of iron oxide have a higher specific gravity.
- Effect of fineness of grinding upon specific gravity is slight. Very finely ground cements are likely to have lower specific gravities.

CHEMICAL LAB TEST

1. Loss on Ignition

- 1.00 g of the sample is heated for 15 minutes in a weighed and covered platinum crucible of 20 to 25 ml capacity by placing it in a muffle furnace at any temperature between 900° and 1000°C.
- Then it is cooled and weighed. Thereafter, the loss in weight is checked by a second heating for 5 minutes and reweighing.
- Loss in the weight is recorded as the loss on ignition and the percentage of loss on ignition to the nearest 0.1 is calculated (loss in weight × 100)
- Percentage loss on ignition should not exceed 4 percent for 53 grade and 5% for 33 + 43 grade.

2. Chemical Composition

- The various tests are carried out to determine the chemical constituents of cement. Following are the chemical requirements of ordinary cement as per BIS:269-1975:

(i) Ratio of percentage of alumina (Al_2O_3) to that of iron oxide (Fe_2O_3): should not be less than 0.66.

(ii) Ratio of percentage of lime to those of alumina, iron oxide and silica: is known as the lime saturation factor.

$$LSF = \frac{CaO - 0.7\,SO_3}{2.8\,SiO_2 + 1.2Al_2O_3 + 0.65\,Fe_2O_3}$$

(iii) The BIS set the LSF requirement as 0.66 lower limit for grade 33 & 43 cement while 0.8 for grade 53 cement.

(iv) The higher value of LSF (1.02) corresponds to a higher content of free lime which makes the concrete vulnerable to sulphate attack and reduces soundness of the concrete.

(v) When LSF is low than specified, the amount of C_3S will also be low resulting in slow setting and slow gaining of strength during early period.

(vi) Total sulphate content as sulphuric anhydride (SO_3)% by mass maximum

- when $C_3A \leq 5$ LSF = 2.5 for all grade of cement
- when $C_3A > 5$ LSF = 3 for all grade (33, 43, 53) cement.

(vii) Insoluble residue% by mass maximum is 4 for 33 grade and 2 for 43 & 53 grade.

(viii) Weight of magnesia: should not exceed 6%. for all grade of cement.

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CONVENTIONAL QUESTIONS

1. Describe the various tests specified for checking the quality of given sample of cement? (1988)

2. How is fineness of cement expressed? What is its role in the strength of cement? (1990)

3. Describe the test to determine the initial setting time of cement. What is its significance? (1990)

4. Name the various test specified for checking the quality of agiven sample of cement. Describe briefly the test for fineness of cement, or soundness of cement. (1993)

5. What are the tests conducted for Portland cement in a laboratory? Describe any one of the methods. (1994)

6. Describe briefly how Portland slag cement is manufactured. What are the ingredients? Write three advantages of Portland slag cement over ordinary Portland cement. (1994)

7. What are initial and final setting times of cement? How are they experimentally determined? Briefly explain the roles of gypsum and calcium chloride in cement. (1995)

8. Explain the purpose of conducting soundness test of cement. Describe the apparatus and method of test with the help of neat sketches. What are the permissible limits of observation in the test? (1996)

9. Name the four important constituents of cement and state the role of each in achieving its properties. (1998)

10. Describe the hydration of Portland cement and outline the ways in which the Vicat apparatus and the Le chatelier apparatus can be used to assess the properties of fresh and hardened pastes. (1999)

11. Explain how sulphate resisting cement and rapid hardening Portland cement differ from ordinary Portland cement and the specific circumstances in which these cements would be used. (1999)

12. Name the principal compounds in Portland cement, their relative rates of reaction with water and their approximate proportions. (1999)

13. List out the products of hydration and their influence on the properties of cement. (2001)

14. Explain the difference between various grades of ordinary Portland Cement. (2002)

15. Explain the compressive strength test of cement mortar and state its importance. (2005)

16. Which are the four important compounds formed during the setting action of cement (four principal minerals in ordinary-Portland cement)? Mention their relative proportions expressed as percentages and also functions of these compounds. (2007)

17. List the various laboratory tests for assesing the quality of cement and their importance. (2008)

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OBJECTIVE QUESTIONS

1. Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

List-I	List-II
A. Fineness of cement	1. Le-Chatelier apparatus
B. Setting time	2. Vicat's needle
C. Soundness	3. Air permeability apparatus
D. Workability	4. Slump cone

Codes :

	A	B	C	D
A.	1	2	3	4
B.	3	1	4	2
C.	3	2	1	4
D.	1	4	3	2

2. If 'p' is the standard consistency of cement the amount of water used in conducting the initial setting time test on cement is

(a) 0.65 p (b) 0.85 p

(c) 0.6 p (d) 0.8 p

3. For complete hydration of cement the water cement ratio needed is

(a) less than 0.25 (b) more than 0.25 but less than 0.35

(c) more than 0.35 but less than 0.45 (d) more than 0.45 but less than 0.60

4. Match **List-I** (Type of cement) with **List-II** (Characteristics) and select the correct answer using the codes given below the lists:

List-I

A. Air entraining Portland cement

B. Low-heat Portland cement

C. Hydrophobic Portland cement

D. Rapid hardening Portland cement

List-II

1. Suitable for very large structures
2. Unsuitable for very large masses of concrete
3. Greater resistance to frost attack
4. Safe storage under unfavourable conditions of humidity

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Codes :

	A	B	C	D
A.	4	2	1	3
B.	3	4	1	2
C.	3	1	4	2
D.	4	1	2	3

5. Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I	List-II
A. Vicat's needle	1. Setting time
B. Michaeli's compound lever apparatus	2. Specific surface
C. Le Chatelier's apparatus	3. Tensile strength
D. Turbidimeter	4. Soundness

Codes :

	A	B	C	D
A.	1	2	3	4
B.	1	3	4	2
C.	2	4	1	3
D.	3	4	1	2

6. What is the requirement of water (expressed as % of cement w/w) for the completion of chemical reactions in the process of hydration of OPC?

(a) 10 to 15% (b) 15 to 20%

(c) 20 to 25% (d) 25 to 30%

7. A cement bag contains 0.035 cubic meter of cement by volume. How many bags will one tonne of cement comprise?

(a) 16 (b) 17

(c) 18 (d) 20

8. Which of the following pairs in respect of Ordinary Portland Cement (OPC) are correctly matched?

1. Initial setting time ... 30 minutes
2. Final setting time ... 10 hours
3. Normal consistency ... 10%

Select the correct answer using the codes given below :

(a) 1, 2 and 3 (b) 2 and 3

(c) 1 and 2 (d) 1 and 3

9. High alumina cement is produced by fusing together a mixture of

(a) limestone and bauxite (b) limestone, bauxite and gypsum

(c) limestone, gypsum and clay (d) limestone, gypsum, bauxite, clay and chalk

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10. Consider the following statements :

High early strength of cement is obtained as a result of

1. fine grinding
2. decreasing the lime content
3. burning at higher temperatures
4. increasing the quantity of gypsum

Which of these statements are correct?

(a) 1 and 2 (b) 1 and 3
(c) 2, 3 and 4 (d) 1, 3 and 4

11. The temperature range in a cement kiln is

(a) 500° to 1000°C (b) 1000° to 1200°C
(c) 1300° to 1500°C (d) 1600° to 2000°C

12. Consider the following statements:

1. Tests on cement paste to determine initial and final setting times are done at normal consistency condition.
2. Low heat cement has a high percentage of tricalcium aluminate.
3. High early strength Portland cement contains a larger percentage of tricalcium silicate and a lower percentage of dicalcium silicate.

Which of these statements are correct?

(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 1, 2 and 3

13. Match List-I (Property of cement) with List-II (Testing apparatus) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Specific gravity	1. Blain's apparatus
B. Setting time	2. Le Chatelier's flask
C. Soundness	3. Compressometer
D. Fineness	4. Autoclave
	5. Vicat's apparatus

Codes :

	A	B	C	D
A.	3	5	1	2
B.	2	5	1	4
C.	2	5	4	1
D.	5	3	4	1

14. Consider the following oxides:

1. Al_2O_3 2. CaO 3. SiO_2

The correct sequence in increasing order of their percentage in an ordinary Portland cement is

(a) 2, 1, 3 (b) 1, 3, 2
(c) 3, 1, 2 (d) 1, 2, 3

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15. Increase in fineness of cement

(a) reduces the rate of strength development and leads to higher shrinkage.

(b) increases the rate of strength development and reduces the rate of deterioration

(c) decreases the rate of strength development and increases the bleeding of cement

(d) increases the rate of strength development and leads to higher shrinkage.

16. Match **List-I** (cement) with **List-II** (Characteristic) and select the correct answer using the codes given below the lists:

List-I	List-II
A. High alumina cement	1. High early strength
B. Blast furnace cement	2. Gypsum free cement
C. Quick setting cement	3. Selenetic cement
D. Rapid hardening cement	4. Used in mass concrete work
	5. Used in chemical factories and mines

Codes :

	A	B	C	D
(a)	5	4	2	1
(b)	4	3	2	1
(c)	5	4	3	2
(d)	4	5	1	2

17. The fineness of cement is tested by

(a) air-content method (b) air-permeability method

(c) Le-Chatelier apparatus (d) Vicat's apparatus

18. The test on cement designed to accelerate the slaking process of the ingredient of cement and to determine the resulting expansion in a short time is

(a) setting time test (b) soundness test

(c) normal consistency test (d) accelerated test

19. Consider the following statements:

High Alumina Cement (HAC)

1. has high early compressive strength and high heat of hydration than OPC-43 grade
2. is not suitable to be used in cold regions

Which of these statements is/are correct?

(a) 1 along (b) 2 alone

(c) Both 1 and 2 (d) Neither 1 nor 2

20. Consider the following statements:

When cement is tested for setting time, on gauging it shows quick setting. This phenomenon known as "Flash set" of cement is due to the presence of high

1. tricalcium aluminate (C_3A) in cement
2. alkalies in cement

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3. tricalcium silicate (C_3S) in cement

Which of these statements are correct?

(a) 1,2 and 3 (b) 2 and 3

(c) 1 and 2 (d) 1 and 3

21. Which one of the following statements regarding the cement fineness is NOT correct?

(a) Fine cement is more liable to suffer from shrinkage cracking than a coarse cement.

(b) Fine cement will show faster rate of hardening than coarse cement.

(c) Fine cement show faster rate of heat evolution and total quantity of heat evolved is much large than coarse cement.

(d) Fine cement shows the same setting time as coarse cement.

22. For marine works, the best suited cement is

(a) low heat portland cement (b) rapid hardening cement

(c) ordinary portland cement (d) blast furnace slag cement.

23. Match **List-I** (Type of cement) with **List-II** (Characteristics) and select the correct answer using the codes given below the lists:

List-I

A. Ordinary portland cement

B. Rapid hardening cement

C. Low heat cement

D. Sulphate resistant cement

List-II

1. The percentage of C_3S is maximum and is of the order of 50%
2. The percentages of C_2S and C_3S are the same and of the order of 40%
3. Reacts with silica during burning and causes particles to unite together and development of strength
4. Preserves the form of brick at high temperature and prevents shrinkage

Codes :

	A	B	C	D
(a)	2	4	1	3
(b)	3	1	4	2
(c)	2	1	4	3
(d)	3	4	1	2

24. Match **List-I** (Type of cement) with **List-II** (Property/Characteristics) and select the correct answer using the codes given below the lists:

List-I

A. High strength portland cement

B. Super sulphated cement

C. High alumina cement

D. Rapid hardening portland cement

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List-II

1. Should not be used with any admixture
2. Is extremely resistant to chemical attack
3. Gives a higher rate of heat development during hydration of cement
4. Has a higher content of tricalcium silicate

Codes :

	A	B	C	D
(a)	3	2	1	4
(b)	4	1	2	3
(c)	3	1	2	4
(d)	4	2	1	3

25. Four main oxides present in ordinary portland cement are : CaO, Al_2O_3, SiO_2 and Fe_2O_3. Identify the correct ascending order of their proportions in a typical composition of OPC.

(a) Al_2O_3, Fe_2O_3, CaO, SiO_2
(b) Al_2O_3, CaO, Fe_2O_3 SiO_2
(c) Fe_2O_3, Al_2O_3, SiO_2, CaO
(d) Fe_2O_3, SiO_2, Al_2O_3, CaO

26. The proper size of mould for testing compressive strength of cemen is

(a) 7.05 cm cube
(b) 10.05 cm cube
(c) 15 cm cube
(d) 12.05 cm cube

27. The specific gravity of commonly available ordinary portland cement is

(a) 4.92
(b) 3.15
(c) 2.05
(d) 1.83

28. A quick-setting cement has an initial setting time of about

(a) 50 minutes
(b) 40 minutes
(c) 15 minutes
(d) 5 minutes

29. Match **List-I** (Type of cement) with **List-II** (Property) and select the correct answer using the codes given below the lists:

List-I	**List-II**
A. Blast furnace slag cement	1. High percentage of tricalcium silicate
B. High alumina cement	2. Initial setting time is approximately three and a half hours.
C. Low heat cement	3. Low percentage of iron oxide
D. White cement	4. Rate of hardening is low

Codes :

	A	B	C	D
(a)	4	3	1	2
(b)	1	3	4	2
(c)	1	2	4	3
(d)	4	2	1	3

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30. Match **List-I** (Type of cement) with **List-II** (Characteristic) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Rapidly hardening cement	1. Lower C_3A content than that in OPC
B. Low heat portland cement	2. Contains pulverised fly ash
C. Portland pozzlana cement	3. Higher C_3S content than that in OPC
D. Sulphate resisting cement	4. Lower C_3S and C_3A contents than that in OPC

Codes :

	A	B	C	D
(a)	1	2	4	3
(b)	3	4	2	1
(c)	1	4	2	3
(d)	3	2	4	1

31. As per specifications, the initial setting time of ordinary portland cement should not be less than
(a) 10 minutes (b) 20 minutes
(c) 30 minutes (d) 60 minutes

32. In cements, generally the increase strength during a period of 14 days to days is primarily due to
(a) C_3A (b) C_2S
(c) C_3S (d) C_4AF

33. Consider the following types of cements:
1. Portland pulverized fuel ash cement
2. High alumina cement
3. Ordinary portland cement
4. Rapid hardening cement

Which one of the following is the correct sequence of the above cements in terms of their increasing rate of strength gain?
(a) 2-3-4-1 (b) 1-3-4-2
(c) 2-1-3-4 (d) 3-1-2-4

34. Ultimate strength of cement is influenced by which one of the following?
(a) Tricalcium silicate (b) Dicalcium silicate
(c) Tricalcium aluminate (d) Tetracalcium alumino-ferrite

35. Why is lime added to cement slurry for the topcoat of plastering?
(a) To improve the strength of plaster
(b) To stiffen the plaster
(c) To smoothen the plaster for ease of spread
(d) To make the plaster non-shrinkable

36. Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

List-I

A. Absorption and surface moisture in aggregates

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B. Deleterious material

C. Grading of aggregate

D. Chemical stability

List-II

1. Interferes with hydration of cement
2. Improves workability of mix
3. Ensures durability of all structures
4. Affects the mix proportions

Codes :

	A	B	C	D
(a)	3	1	2	4
(b)	4	2	1	3
(c)	3	2	1	4
(d)	4	1	2	3

37. Consider the following statements:

1. Setting and hardening of cement takes place after the addition of water.
2. Water causes hydration and hydrolysis of the constituent compounds of cement which act as binders.

Which of these statements is/are correct?

(a) 1 only (b) 2 only

(c) Both 1 and 2 (d) Neither 1 nor 2

38. Match List-I (Composition of raw material used in manufacture of cement) with List-II (Component of raw material) and select the correct answer using the codes given below the lists:

List-I	List-II
A 25%	1. Silica
B. 65%	2. Calcium oxide
C. 5%	3. Aluminium oxide
D. 5%	4. Ferrous and magnesium oxides

Codes :

	A	B	C	D
(a)	1	2	3	4
(b)	4	3	2	1
(c)	1	3	2	4
(d)	4	2	3	1

39. Match **List-I** (Compound) with **List-II** (Proportion) and select the correct answer using the codes given below the lists:

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List-I	List-II
A. Tricalcium silicate	1. 25 to 30%
B. Dicalcium silicate	2. 50 to 60%
C. Tricalcium aluminate	3. 6 to 8%
D. Tetra calcium alumino ferrite	4. 8 to 12%

Codes :

	A	B	C	D
(a)	2	3	4	1
(b)	4	1	2	3
(c)	2	1	4	3
(d)	4	3	2	1

40. Consider the following statements:

1. Rise in temperature does not cause any change in the colour of cement concrete.
2. Curing minimizes the shrinkage of cement concrete when it sets.

Which of these statement is/are correct?

(a) 1 only (b) 2 only

(c) Both 1 and 2 (d) Neither 1 nor 2

41. Consider the following statements:

Low percentage of C_3S and high percentage of C_2S in cement will result in

1. higher ultimate strength with less heat generation
2. rapid-hardening
3. better resistance to chemical attack

Which of these statements are correct?

(a) 1 and 2 (b) 2 and 3

(c) 1 and 3 (d) 1,2 and 3

The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason(R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) Both A and R are true and R is the correct explanation of A

(b) Both A and R are true but R is not a correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

42. Assertion (A) : **Flash set is the stiffening of the cement paste within a few minutes after mixing.**

Reason (R) : Flash set occurs due to insufficient gypsum to control the rapid reaction of C_3A with water.

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43. **Assertion (A) :** The amount of cement paste should be sufficient to cover the surface of all particles for proper workability and bond.

Reason (R) : The water-cement ratio isfixed accordingly.

44. **Assertion (A) :** The greater the surface area of a given volume of cement the greater the hydration

Reason (R) : The reaction between the water and cement starts from the surface of the cement particles.

45. **Assertion (A) :** A low C_3A cement generates less heat and develops higher ultimate strength.

Reason (R) : During setting and hardening, the amount of lime liberated appears to be about 15 to 20 per cent by weight of cement.

46. **Assertion (A) :** Low heat portland cement is used in dam constructin.

Reason (R): Low heat portland cement attains higher 28 days strength than ordinary portland cements.

47. **Assertion (A):** The rate of hydration is faster in finer cements.

Reason (R): The surface area finer cement is more in case of finer cement.

48. **Assertion (A):** Low heat cement is used in the construction of large dams.

Reason (R) : Very high compressive strength is achieved by low heat cement in 28 days.

49. **Assertion(A) :** The tests for determining the setting times of cements are of little use in assessing the hardening of cement concret.

Reason (R) : Ultimate strength of concrete in-situ is not dependent upon the setting times of cement used.

ANSWERS

1.	(c)	2.	(b)	3.	(c)	4.	(c)	5.	(b)	6.	(c)	7.	(d)
8.	(c)	9.	(a)	10.	(b)	11.	(c)	12.	(b)	13.	(c)	14.	(b)
15.	(d)	16.	(a)	17.	(b)	18.	(b)	19.	(a)	20.	(d)	21.	(d)
22.	(d)	23.	(b)	24.	(c)	25.	(c)	26.	(a)	27.	(b)	28.	(d)
29.	(c)	30.	(b)	31.	(c)	32.	(c)	33.	(c)	34.	(b)	35.	(d)
36.	(d)	37.	(c)	38.	(a)	39.	(c)	40.	(c)	42.	(a)	44.	(d)
46.	(c)	47.	(a)	48.	(c)	49.	(b)						

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CHAPTER

2

Concrete

INTRODUCTION

- Concrete is a composite man made material and is most widely used building material in the constuction industury.
- It is a mixture of binding material such as lime or cement, well graded coarse and fine aggregate, water and sometime admixture.
- Most of the ancient structures and historical buildings had been constructed with lime concrete but with the invention of cement, use of lime concrete is limited to making bases of concrete foundations and roof teracing.
- Also production of good concrete is found difficult. Now a question arise what is "Good concrete".
- Basic requirement of Good concrete is that it should be satisfactory in its hardened state, and also in its fresh state while being transported from mixture and placed in form work.
- In fresh state, consistency of mix should be such that it can be compacted by the desired means without excessive effort, and also the mix should be cohesive enough for the methods of transporting and placing used so as not to cause segregation.
- In hardened state satisfactory compressive strength and an adequate durability is required.

CLASSIFICATION

1. Based on Cementing Material

(a) Lime concrete

(b) Gypsum concrete

(c) Cement concrete

2. Based on Perspective Specification

- Cement concrete is specified by proportions of different ingredients, e.g., 1 (cement) : 1.5 (fine aggregate) : 3 (coarse aggregate).
- It is presumed that by adhering to such perspective specifications satisfactory performance may be achieved.
- This type of concrete mix is also known as nominal mix.
- Conventional nominal mix proportions have limited significance, since the quantity of fine aggregate is fixed irrespective of the cement content, water-cement ratio and the maximum size of aggregate to be used.

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Mix Proportions of Cement Concrete

Grade of concrete	M10	M15	M20	M25
Mix Proportion	1:3:6	1:2:4	1:1.5:3	1:1:2
Perspective characteristics Strength (N/mm²)	10	15	20	25

- Here M refers to mix. IS-456 restricts use of nominal mix upto M-20 grade only.

3. Based on Performance oriented specification

- When the concrete properties such as strength, water-cement ratio, compaction factor, slump, etc., are specified then concrete can be classified as designed-mix concrete.
- In a design mix concrete the mix is designed to produce the grade of concrete having the required workability and a characteristic strength not less than the specified values.

4. Based on Grade of cement concrete.

- On the basis of strength (N/mm^2) of concrete cubes (150 mm) at 28 days , concrete is classified as.

Grade of Cement Concrete

Grade	M5	M7.5	M10	M20	M25	M30	M35	M40	M45	M50	M55
Characteristic Strength	5	7.5	10	20	25	30	35	40	45	50	55

- Further we can classify these on the basis of their strength.

(a) Low strength concrete $(< 20\ N/mm^2)$

(b) Medium strength concrete $(20-40\ N/mm^2)$

(c) High strength concrete $(> 40\ N/mm^2)$

5. Based on Bulk density

Extra Light weight	$< 500\ kg/m^3$
Light weight	$500-1800\ kg/m^3$
Dense weight	$1800-2500\ kg/m^3$
Super Heavy weight	$> 2500\ kg/m^3$

6. Based on place of casting

1. **In-situ concrete :** When concrete is placed in position at the site it is known as In-situ concrete.
2. **Precast concrete :** When concrete is used for making prefabricted units in a factory is called as precast conerete.

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MANUFACTURING OF CONCRETE

- As discussed before concrete is a mixture of cement, aggregate, and water.
- Each of the above constituent has a special function.
  - (a) **Cement :** It imparts adhesive and cohesive properties to concrete and binds various ingredients into a compact whole.
  - (b) **Aggregate :** They form body of concrete and occupy 70 – 80% volume of concrete. They are further classified as fine and coarse aggregate.
  - (c) **Water :** It causes hydration of cement.
- For uniform strength of concrete the various stages of concrete production are
  1. Batching or measurement of materials
  2. Mixing
  3. Transporting
  4. Placing
  5. Compacting
  6. Curing
  7. Finishing

1. Batching

- Aggregates, cement and water should be measured with an accuracy of ± 3 per cent of batch quantity and the admixtures by 5 per cent of the batch quantity.
- There are two prevalent methods of batching materials are
  - (a) Volume batching
  - (b) Weigh batching.
- For most important works weigh batching is recommended.
- Volume batching is generally recommended for small jobs only.

Volume batching

- Amount of each solid ingredient is measured by loose volume using standard box known as gauge box.
- For example, volume of moist sand in a loose condition weighs much less than the same volume of dry compacted sand.
- Therfore correction for bulking of sand is done if volume batching is adopted.

Weighing Batching

- In weigh batching water is not added by graduated buckets as the water may spill over during its addition. A horizontal or vertical tank is fitted to the mixer.
- Cement is always measured by weight, irrespective of method of batching.
- Water is measured in kg or liters as density of water is 1 kg/liter.
- Volume of 1 bag of cement is 0.035 m^3(or sometime also said 35 liters).

2. Mixing

- Objective of mixing is to obtain homogenous and uniform colour concrete of desired strength.
- Mixing time depends on the type and capacity of mixer but IS-456 suggest approximately mixing time as 2 min.

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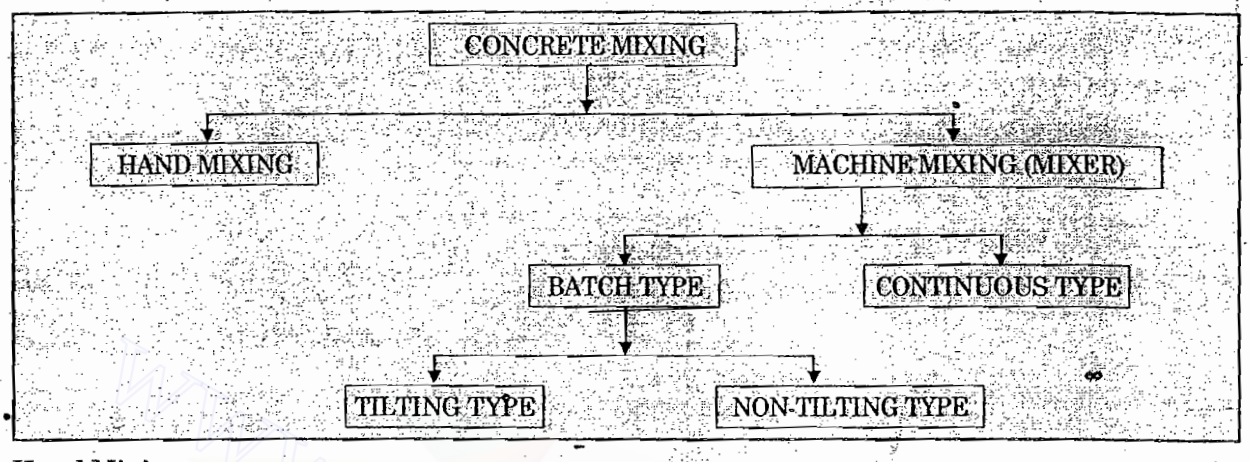
- Generally 20 revolution of concrete in mixture provides sufficient mixing.
- A poor quality of concrete is obtained if mixing time is reduced whereas if it is increased it is un economical.
- If mixing time is increased to 2 minutes the compressive strength of concrete produced is enhanced and beyond this time the improvement in compressive strength is insignificant and prolonged mixing may cause segregation as, due to longer mixing periods the water may get absorbed by the aggregates or evaporate resulting in loss of workability and strength.
- Mixing is either done by hand or by machine mixing.



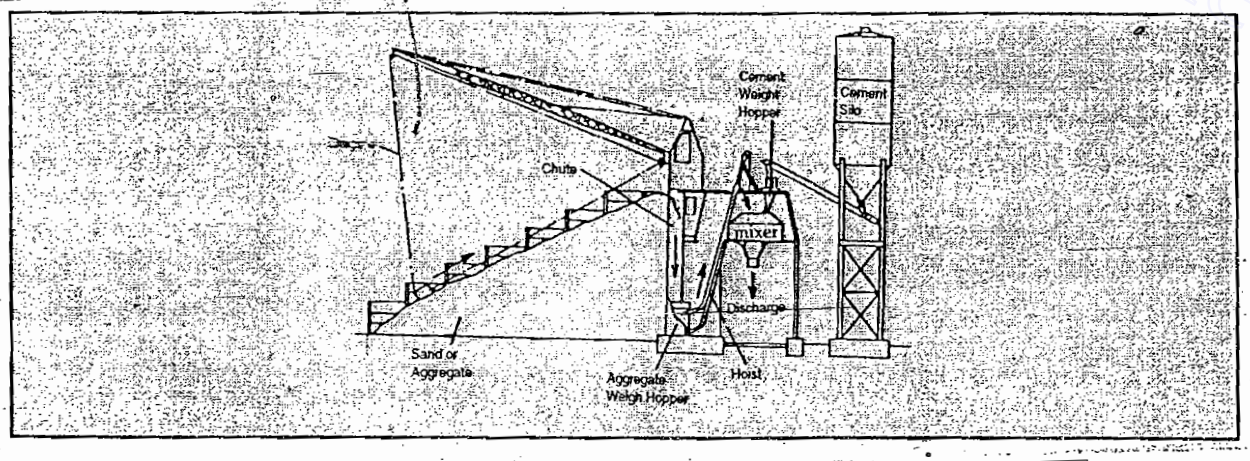
Hand Mixing

- Hand mixing is adopted for small jobs where the quantity of concrete involved is small.
- Mixing time should be approximately 2 minutes and should never exceed 3 min.

Machine mixing

- When a large quantity of concrete of the desired quality is to be produced, the machine mixing becomes imperative as Concrete can be produced at a faster rate with better quality.
- Machine used for production of concretes are
  - (a) Batching plant.
  - (b) Continous mixers
  - (c) Tilting type.
  - (d) Non tilting type.

(a) Batching plant



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- These plants consists of all arrangements for receiving raw material of concrete from storage bins, weighing out each ingredient for each batch of the mix, and mixing the ingredients thoroughly to form a concrete of required specification.
- Batchers are available in three categories i.e
  (a) Manual
  (b) **Semi-automatic :** In semi-automatic batching, the charging and discharging of the batchers are activated manually but are automatically terminated.
  (c) **Fully automatic :** A single starter switch activates the batching sequence, the weights and volumes of which have been previously programmed into the system.
- Other types of Mixers are:

Concrete Mixers

- Mixing time is usually 2 to 3 minutes.
- Some mixers have a timing device which controls the mixing time and does not permit discharge from it till mixing for specified time is completed.
- Concrete mixers are specified by the volume of mixed concrete discharged after mixing of each batch, expressed in m^3 (such as 0.25, 0.38, 0.57, 0.75, 1.5, 2.25 and 3 m^3).
- Sometimes the total volume of the unmixed ingredients in m^3 is given as a prefix. i.e. 1.0/0.75 mixer takes 1 m^3 of unmixed material and gives 0.75 m^3 of mixed concrete in each batch.

TYPES OF CONCRETE MIXERS

- There are two main types of concrete mixers:
  (i) Drum type
  (ii) Pan type

(i) Drum Type Concrete Mixers

- Drum type mixer are of three types
  (a) Tilting
  (b) Non-tilting
  (c) Reversing
- Standard type of these mixtures available are as follows. these are designated by a number representing its nominal batch capacity in liters.

Tilting (T)	:	85T , 100T , 140T , 200T
Non-Tilting (N T)	:	200NT , 280NT , 340 NT , 400 NT , 800 NT ,
Reversing (R)	:	200 R , 280 R, 340 R , 400 R

Note: Sometimes the mixers are specified by two quantities, the total volume of ingredients added and the volume of concrete produced. For example 285/200-litres mixer takes 285 litres of ingredients and yields 200 liters of concrete.

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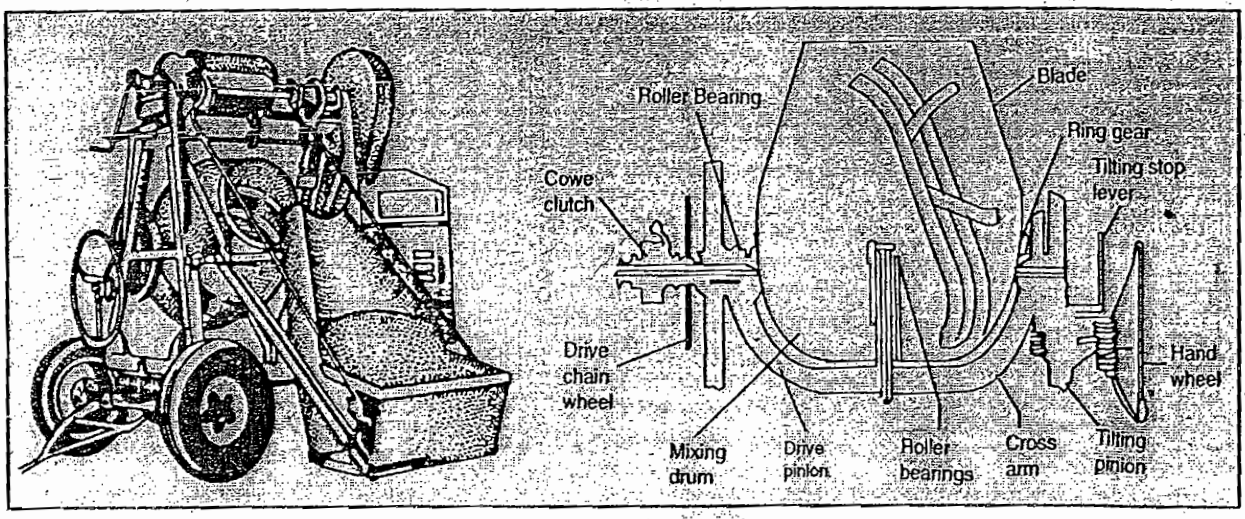
Tilting mixer



- In this mixed concrete is discharged by tilting the drum about the horizontal axis.
- Tilting mixers are useful for large construction works.
- Tilting mixers are easier to clean and can discharge the mix quickly and with minimum segregation.
- It gives better results even with dry concrete.
- It can be used for aggregate size more than 75 mm.

Non-tilting mixer

- Non-tilting mixer is equipped with a drum rotating about a horizontal axis. This drum is supported on rollers and is commonly driven through a ring gear on the drum periphery.
- Blades are fixed inside the drum in such a way that it facilitates the discharge of mixed concrete. These blades also assist in mixing up of the concrete.
- The drum is charged either through an opening opposite to the discharge opening with the help of a loading skip as in the case of the tilting type mixers or through the same opening which serves for both feeding the mix ingredients and discharging the mixed concrete
- Non-tilting mixers are Suitable for small works.
- Non-tilting mixers cannot be used when aggregate size is more than 75 mm.

Reversing Mixer

- These are also known as forced action type mixers and are used for large size works.
- It has horizontal non-tilting type drum with two sets of blades.
- One set of blades mixes the mix while drum is rotated in one direction. and second set of blades discharges the mix when the drum is reversed.

(ii) Pan Type Concrete Mixers

- In the pan type mixer, an open pan equipped with a rotating star of blades moves in a opposite direction relative to each other with at very low speed.
- These mixers are very efficient in working, especially with stiff mixes.
- In some models the pan may be stationary and only the blades may move.

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Note: Paving Mixers :

- These mixers are used for concreting of rigid pavements.
- They are mounted on crawler tracfors
- These may have single or double compartments drums.
- Standard size of single compartment paving mixers are 27E and 34E, and that of double compartments mixers are 16E and 34E, as per ASTM specification.
- E stands for paving mixers and number denotes the nominal volume of mixed concrete is cubic feet in one batch.

3. Transporting

- Specification states that the process of mixing, transporting, placing and compacting the concrete should not take more than initial setting time of cement (30 minutes using O.P.C.).
- It must also ensure that segregation not took place.

Methods of transporting concrete

(a) Pans: Rcommended only for small jobs.

(b) Wheel Barrows : (Hand Buggies)

- For moderate distance and medium size jobs, steel wheel barrows with pneumatic tyres may be used.

(c) Power Buggies

- Hand Buggies are driven manually where Power Buggies are driven by some prime mover.
- These have speed up to 24 km.p.h. and can climb up to 20%.

(d) Tower bucket

- Vertical hoist in the form of tower is erected and wheel barrows move within guide rails. Capacity is 0.226 to 1.02 cum. Advantages of this type are:
  (i) Initial cost is less
  (ii) It requires less space, so used in congested area.

(e) Crane bucket

- Hoisting is facilitated by a crane and the bucket capacity varies from 0.38 to 6.1 cum.
- Crane hoisting is economical in the long run although its initial cost is high.

(f) Dump Truck

- Concrete if air-entrained can be safely transported by dump trucks without any agitation.

(g) Chutes

- When concrete is to be deposited below ground level at a higher depth, it can be discharged through a steel shaft called chute.
- Height of fall is avoided.

(h) Concrete Pumps

- This method is commonly used on tunnel works and on locations which are not easily accessible.

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- Concrete can be pumped for a distance of about 400 m, horizontally, and 80 m vertically having slump vlaue 50 mm to 100 mm.
- The diameter of pipe varies from 10 cm to 20 cm depending upon the maximum size of coarse aggregated used.

(i) Transit mixer :

- Transit mixer is a truck on which a concrete mixer is mounted whose capacity is 0.76 to 5.7 cum.
- It is used in the situation where concreting is to be done in the built up and busy area and storage space is scarce.
- Usual speed of drum is 2–6 rpm.

(j) Agitating Truck

- If the unit is used to haul ready mixed concrete which requires agitation on route to prevent it from segregation, the unit is called agitator truck. During summer when the temperature is high, ice-cold water is used to keep the temperature low to prevent its setting.
- The standard specifications for ready-mixed concrete requires that the concrete must be delivered from the agitator truck within 1.30 hrs after the water is to mixed the ingredients.

(k) Belt-conveyer

- A belt conveyer is used when the concrete is to be transported continuously and to an inaccessible area.
- The concrete should be of stiff consistency having a slump of not more than 50 mm.
- A common width of belt conveyer is 60 cm and speed is about 80 m/minute.

Advantages	Disadvantages
(i) Uniform flow of concrete	(i) Tendency to segregate concrete
(ii) High capacity	(ii) Badly affected by inclement weather.

4. Placing

- Reasearch has shown that delayed placing of concrete results in a gain in ultimate compressive strength provided the concrete can be adequately compacted.
- For dry mixes in hot weather delay of half to one hour is allowed whereas for wet mixes in cold weather it may be several hours.
- Various situations in which concrete is placed are:-

(a) Mass Concreting

- When the concrete is to be laid in mass as for raft foundation, dam, bridge, pier etc. Concrete is placed in layers of 350–450 mm thickness.
- When the concrete is subjected to lateral thrust, *bond bars* or *bond stones* are provided to form a key between different layers.

(b) Foundations, Beams, Columns, Slabs, Concreting Highways and Runways

(c) Under Water Concrete

- Best method of under water concreting is with the use of tremie pipe, concrete is poured into it with the help of funnel and bottom end is closed with a thick polythene, with the bottom end of pipe at the place of deposition.

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- As pipe is completely filled by concrete (Slump 150-200mm), pipe is slightly lifted and given a jerk causing tearing of polythene sheet and results in discharge of concrete.

5. Compaction

- The process of removal of entrapped air and of uniform placement of concrete to form a homogeneous dense mass is termed compaction.
- The density and consequently the strength and durability of concrete depends upon the quality of compaction.
- The presence of even 5% and 10% voids in hardened concrete left due to incomplete compaction may result in a decrease in compressive strength by about 30% and 60% respectively.

Compaction of the concrete can be achieved in four ways.

(i) Hand Rodding

(ii) High pressure and shock

(iii) Centrifugation or spinning

(v) Mechanical vibration: Reduces the internal friction between the different particles of concrete by imparting oscillation (in the form of SHM) to the particles and thus consolidates the concrete.

The various types of vibrators used are

(a) **Immersion or needle vibrators:**

- Most commonly used.

(b) **External or shutter vibrator**

- These vibrator called form vibrators are clamped rigidly to the form-work at the predetermined points so that both the form and concrete are vibrated.
  - It can compact up to 450mm from the face.
  - It is used for the precasting of thin in-situ section of such shape and thickness as cannot be compacted by immersion i.e. internal vibrator.

(c) **Surface vibrator:**

- It is placed directly on the concrete mass for the compaction of shallow elements i.e. depth ≤ 250mm. Ex- Road surfaces, plain concrete floors etc.
- Very dry mixes can be most effectively compacted since it acts in the direction of gravity, thereby minimizing the tendency for segregation.

(d) **Vibrating Table:** It is very efficient in compacting stiff and harsh concrete mixes required for the manufacture of precast elements.

6. Curing

- Cement gains strength and hardness because of the chemical action between cement and water.
- The water in a concrete mix takes one of the following three forms; as a consequence of hydration are:

(i) ***Combined water:*** Which is chemically combined with the products of hydration; it is non-evaporable.

(ii) **Gel water:** Which is held physically or adsorbed on the surface area of the cement gel.

(iii) **Capillary water:** Which partially occupies the 'capillary pores' that constitute the space in the cement paste remaining after accounting for the volumes of cement gel and unhydrated cement; this water is easily evaporated.

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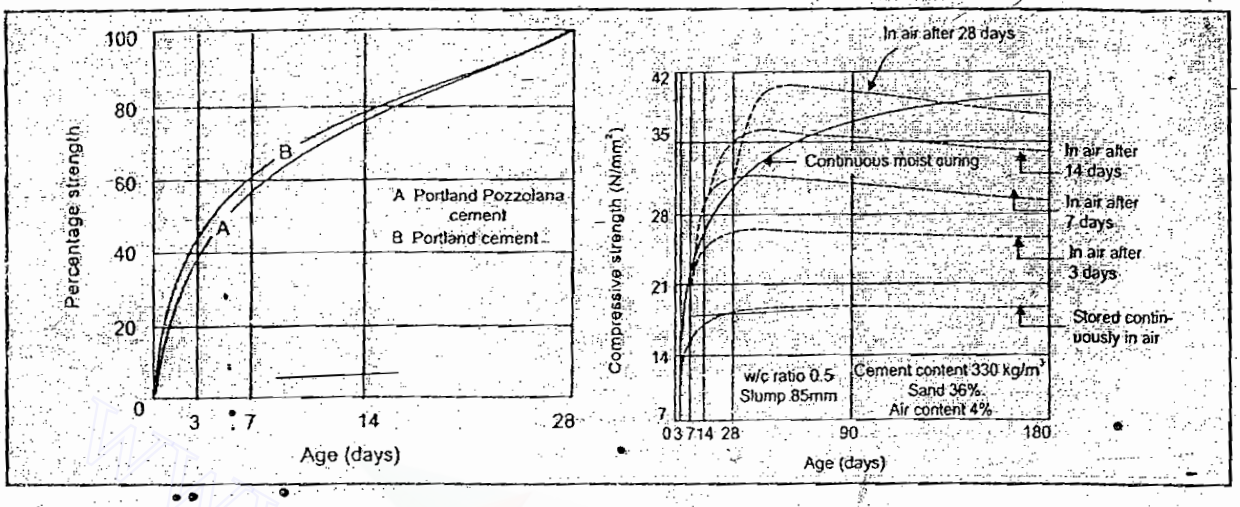
- Curing is name given to procedures that are imployed for actively promoting the hydration of cement in a suitable environement during early stages of hardining of concrete.
- IS: 456 define curing as the process of preventing the loss of moisture from the concrete while maintaing a satisfactorly temperature regime.
- Curing of freshly placed concrete is very important for optimum strength and durability. The major part of the strength in the initial period is contributed by the clinker compound C_3S and partly by C_2S, and is completed in about 3 weeks.



- Curing must be done for at least three weeks and in no case for less than ten days.
- Increase in strength of concrete is very rapid from 3 to 7 days and continues slowly for indefinite period.
- It has be observed that moist cured concrete for 7 days is nearly 50% stronger than that which is exposed to dry air for entire period.
- If concrete is cured for one month, strength is nearly double than that of conrete exposed to dry air.

Objective of Curing

(i) To keep capillary pores saturated, to ensure hydration of cement to increases durability and impermeability of concrete and reduce the shrinkage.

(ii) It improves wear resisting and weather resisting qualities.

(iii) To prevent the loss of moisture from concrete due to evaporation or any other reason, supply additional moisture or heat and moisture to accelerate the gain of strength.

Methods of curing

(i) Shading concrete work.

(ii) Covering concrete surface with wet hessian or gunny bags.

(iii) Sprinkling water on concrete surface.

(iv) Ponding method : It is best method and generally used in practice.

(v) Steam curing recommended for precast concrete members.

(vi) Applying curing compounds.

- As per IS : 456, concrete members shall be kept under curing for a minimum period of 7 days. For OPC (7 to 14 days) at 90% humidity.
- Curing temperature : 5°C to 28° C.

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Note: Lower temperature reduces the rate of setting and higher temperature reduces the ultimate strength.

Steam Curing

- For concrete, mixes with water-cement ratio ranging from 0.3 to 0.7, the increased rate of strength development can be achieved by resorting to steam curing.
- This method of curing is also known as *accelerated* curing since an increased rate of strength development can be achieved.
- Concrete members are heated by steam at 93 °C either at low pressure or high pressure
- By low pressure steam curing about 70 per cent of the 28 day compressive strength of concrete can be obtained in about 16-24 hours and high pressure steam curing is usually applied to precast concrete members and gives 28 day compressive strength at 24 hours.
- It also results in increased resistance to sulphate action and to freezing and thawing.
- Mixes with low water-cement ratio respond more favourably to steam curing than those with higher water/cement ratio.
- Early rise in temperature at the time of setting of concrete may be detrimental because the green concrete may be too weak to resist the air pressure set up in the pores by the increased temperature.
- Rate of increase or decrease of temperature should not exceed 10 to 20° C per hour to avoid thermal shocks.
- Steam curing should be followed by water curing for a period of at least 7 days. This supplementary wet curing is found to increase the later age strength of steam-cured concrete by 20 to 35 per cent.
- Rapid gain of strength can be obtained with the help of infra red radiation than even with steam curing.
- Rapid initial rise of temperature does not affect the ultimate strength.

Applying Curing Compounds

- The curing compounds sprayed on the set concrete surface to prevent the evaporation of water are acrylates, chlorinated rubbers, bitumens, sodium silicate (water glass), linseed oils, wax.
- They make a film, fill the pores, seal the surface voids and prevent evaporation.
- Correct time to apply the membrane is when the water sheet disappears from the surface of the finished concrete.

Effect, of Improper Curing: Following are the major disadvantages of improper curing of concrete.

(i) The chance of ingrees of chlorides and chemicals are very high.

(ii) The cracks are formed due to plastic shrinkage.

(iii) The rate of carbonation increases.

(iv) The durability decreases due to high permeability.

7. Finishing

- Finishing is defined as the process of levelling and smoothing the top surface of freshly placed concrete to achieve the desired appearance is done by as follows:

(i) **Screeding:** Striking off the excess concrete to bring the top surface up to proper grade is called screeding.

(ii) **Floating:** Removing the irregularities on the surface of concrete which are left screeding and it is done by a wooden float about 1.5m long and 20cm wide attached with a handle.

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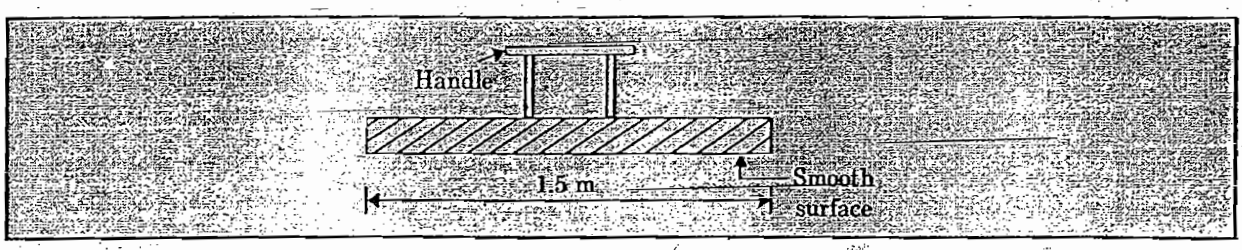


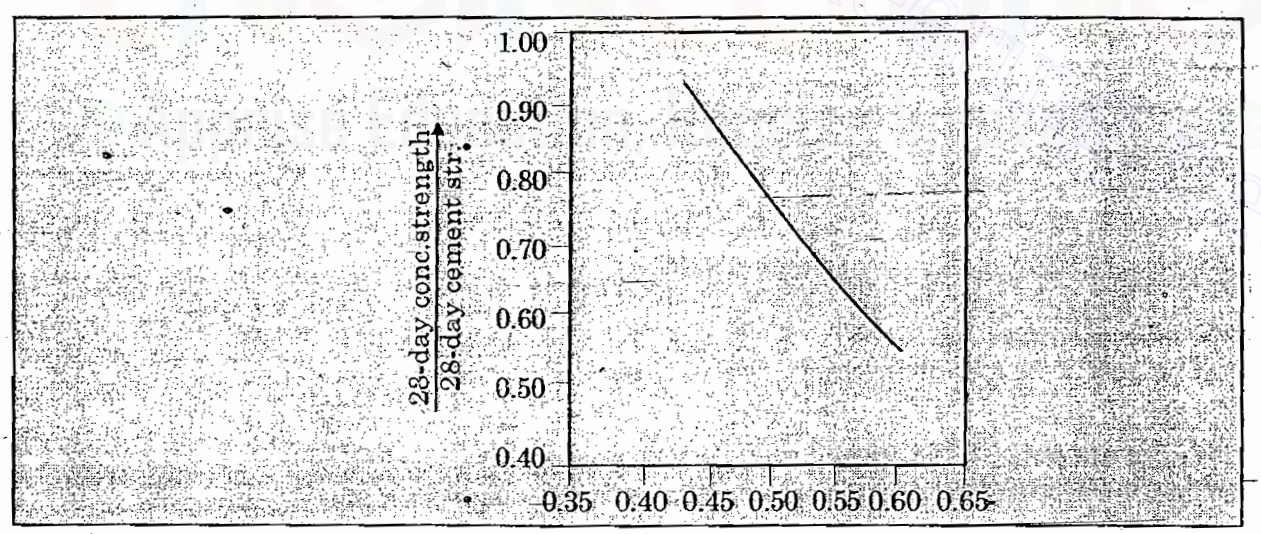
(iii) **Trowelling:** Final operation of finishing be done after all excess water has evaporated by steel float in conical shape gives a very smooth finish.

Maturity of Concrete

- The strength of concrete depends on both the period of curing (i.e. age) and temperature during curing.
- The product (period × temperature) is called the maturity of concrete.
- It is measured in °C hours or °C days.

WATER-CEMENT RATIO

- Water-cement ratio (w/c) is one of the major factor, but not the only one influencing the strength of concrete. It is responsible mainly for the porosity of the hardened cement paste.
- Water -cement ratio, defined as the mass of 'free water' (i.e., excluding that absorbed by the aggregate) to that of cement in a mix, is the major factor that controls the strength and many other properties of concrete.
- In practice, this ratio lies generally in the range of 0.35 to 0.65, although the purely chemical requirement (for the purpose of complete hydration of cement) is only about 0.25.
- Abram law states that compressive strength of hardened concrete is inversely proportional to the water-cement ratio, provided the mix is of workable consistency.
- It is also observed that water-cement ratios of 0.4, 0.5 and 0.6 are expected to produce respectively 28-day concrete strengths that are about 0.95, 0.72 and 0.55 times the 28-day strength of the cement used.



- When W/C is decreased to less than 0.4 there is improper consistency and workability of cement and honeycombed structure.

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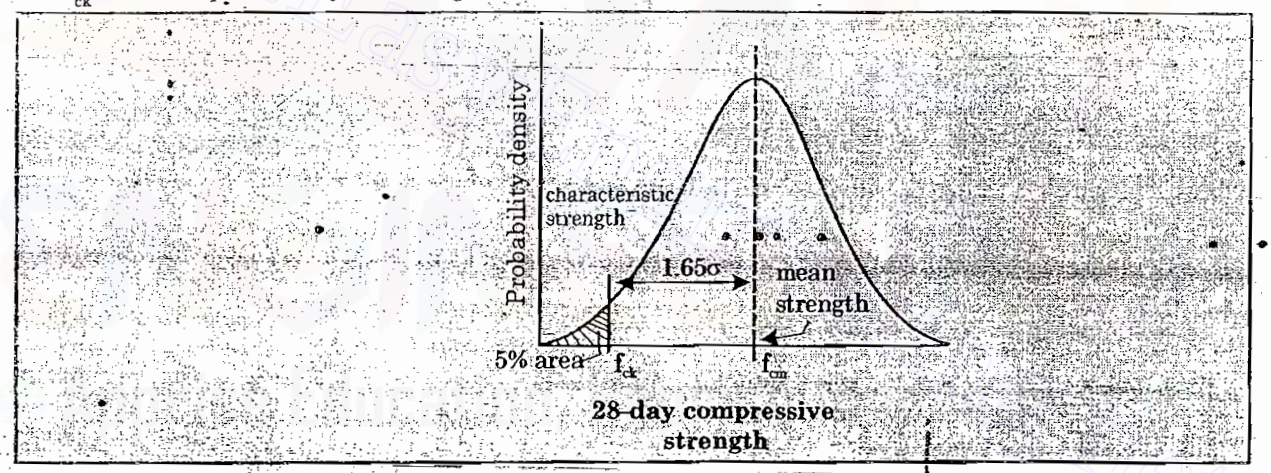
- But concrete compacted by vibrator displays higher strength even up to w/c = 0.3. Ratio more than 0.6, the increase in volume of hydrated products will not be able to occupy the space already filled with water. Therefore porosity increase and strength decreases.

STRENGTH OF CONCRETE

- Quality or grade of concrete is designated in terms of a numbers, which denotes it characteristic compressive strength (of 150 mm cubes at 28-days), expressed in MPa (or, equivalently, N/mm²).
- Number is usually preceded by the letter 'M', which refers to 'mix'. For example , M 20 grade concrete denotes a concrete whose mix is so designed as to generate a characteristic strength of 20 MPa.
- Till date no relation exists between compressive, tensile, bending, and shear strengths of concrete.
- But it is observed that tensile and bending strength of the concrete are of the order of 10 and 15 per cent, respectively of the compressive strength and shear is approximately 20 per cent of the uniaxial compressive strength.
- Characteristic strength is defined as strength of material below which not more than 5% of test results are expected to fall.
- It means that accordingly, the mean strength of the concrete f_{cm} (as obtained from 28-day compression tests) has to be significantly greater than the 5 percentile characteristic strength f_{ck} that is specified by the designer



- Since the strength of concrete is related to the structure of hardened cement paste, it assumes more importance. Indian Standard specifies compression test, flexure and test tensile strength test for assessing the strength of concrete.

Compressive Strength test

- Cement, fine aggregate and coarse aggregate (up to 38 mm) to be used for making concrete are weighed in the ratio to be used in the field and are of hand mixing or by machine mixing.
- Now Water is added and the entire batch mixed until the concrete appears to be homogeneous and has the desired consistency test specimens recommended are 150 × 150 × 150 mm cubes or cylinders of 150 mm diameter and 300 mm height.
- Mixed concrete is filled into the moulds in layers of 50 mm and each layer is tamped with bar, 16 mm in diameter and 600 mm long, 35 times or with a vibrator.

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- Test specimens are stored at a temperature of 27± 3°C at 90% humidity for 24 ±½ hour from the time of addition of water to the dry ingredients.
- After this time specimens are removed from the moulds and placed in water and kept there until taken out just before the test.
- Usually specimens are tested for 7 days or 28 days strength but IS code only suggest 28 days strength only.
- Specimen is placed between the plates of the compression testing machine with the care that the axis of specimen is aligned with the centre of thrust of the spherically seated plate.
- Compression testing machine should be able to apply gradual load of 14 N/mm²/ minute. Until the specimen is crushed.
- Average of the three values is taken as the compressive strength of concrete, provided the individual variation is not more than ± 15 per cent of the average.

Note: Is code also recommends use of cubes of size 100 × 100 × 100 mm provided the aggregate size does not exceed 19 mm.

Influence of Size of Test Specimen

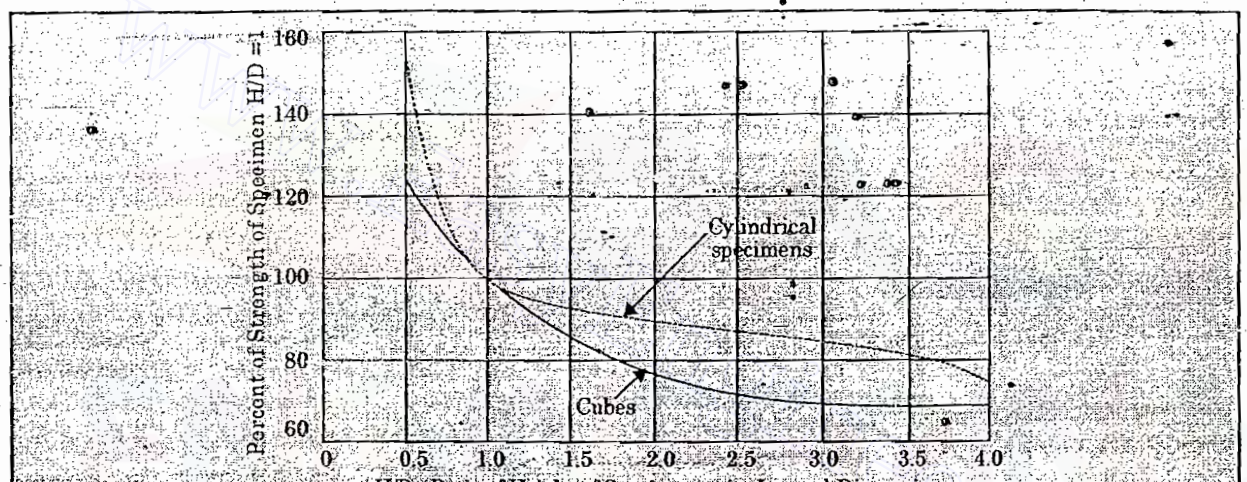

Fig. Effect of height/lateral dimension ratio of specimen on the compressive strength

- The cylinders (150 Dia & 300 height) and prism (100×100×500mm) of a ratio of height or length to the lateral dimension 2 gives strength of about 75 to 85% of the cube strength of normal-strength concrete.
- The cube strength is ≈ 1.25 times cylinder strength.

Flexural Tensile Strength Test

- Flexural tensile strength test is done to determine the tensile load at which concrete may crack.
- It is an indirect test for assessing the tensile strength of concrete.
- Same material is used, as used for compressive strength test.
- Further concrete is filled in the mould of size 150 × 150 × 700 mm and compacted with the tamping bar weighing 2 kg, 400 mm long and with a ramming face 25 mm square.
- Specimen is placed in the testing machine on two 38 mm diameter rollers with a c/c distance of 600 mm. Then load is applied through two similar rollers mounted at the third points, i.e., spaced at 200 mm c/c.

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- Specimen are stored in water at a temperature of 27± 3°C for 48 hours before testing and are tested in wet condition.
- Load is applied without shock and increasing continuously at a rate of 0.7 N/mm²/minute until the specimen fails.

$$\text{Modulus of ruputure} = \frac{pl}{bd^2}(a > 200\text{mm})$$

or,

$$= \frac{3pa}{bd^2}(280\text{mm} < a > 170\text{mm})$$

Where,

a = distance between the line of fracture and the nearest support

b and d = width and depth of specimen,

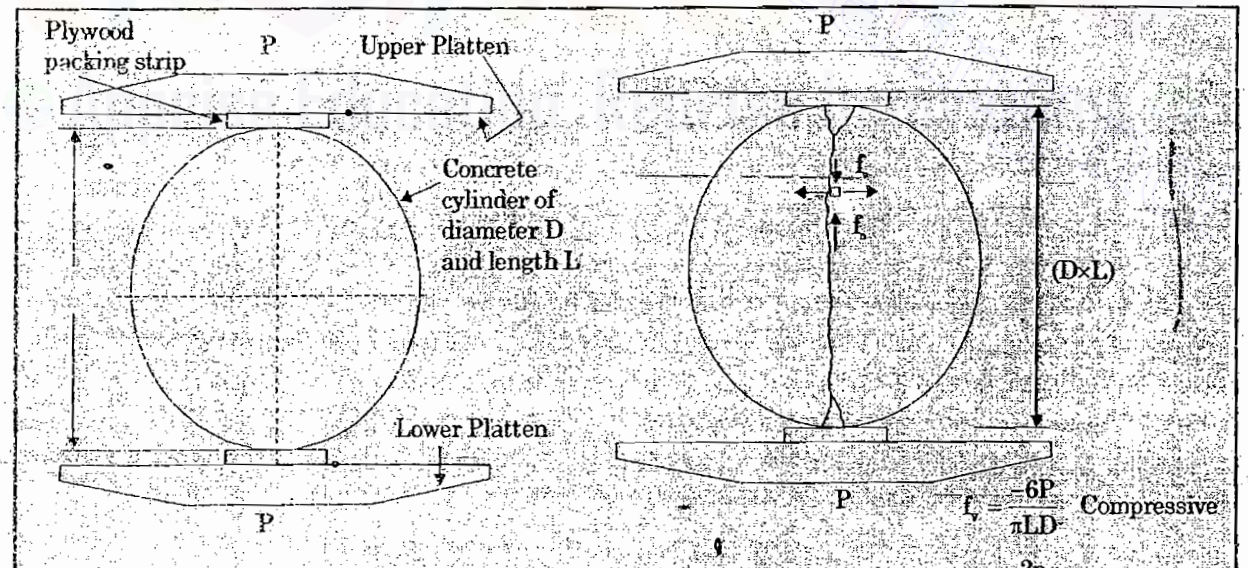
l = length of the span on which the specimen is supported

p = maximum load applied to the specimen.

Note:
- I.S code also recommends use of specimens of size 100 × 100 × 500 mm provided the largest nominal size of aggregate size does not exceed 19mm.
- It is observed that concrete made with crushed rock aggregate tends to have a higher transverse strength than concrete of the same compressive strength made with sand and gravel; thus if a concrete is required for its transverses strength, economical mix may be possible if crushed rock aggregate is used.

Split Tensile Strength test

- As is practically very difficult to apply uniaxial tensile load, therefore few indirect methods are developed to determine tensile strength for example split tensile strength test
- In split tensile strength test a compressive force is applied to the specimen such that specimen fails due to induced tensile stresses.
- Specimen is made of cylindrical shape with the diameter not less than 4 times the maximum size of coarse aggregate and not less than 150 mm. Length of cylinder varies from one to two diameters.



$f_c = \frac{-6P}{\pi LD}$ Compressive

$f_t = \frac{2p}{\pi LD}$ Tensile

Loading Arrangement of Split Tensile Strength Test

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- Load is applied at a rate so as to produce a tensile splitting stress of about 2.0 N/mm²/minute until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained.
- Specimen fails finally by splitting along the loaded diameter and maximum load applied is recorded.
- $$T = \frac{2P}{\pi DL} = \frac{0.637P}{DL}$$

  Where P = maximum load in N applied to the specimen

  D = diameter of specimen in mm

  L = length of the specimen in mm

FACTORS AFFECTING STRENGTH OF CONCRETE

1. Size of specimen

- It is observed that a cube 150 mm of concrete is expected to have 25% more strength than a cylinder specimen (150mm dia, 300mm height).
- If size of cube is decreased compressive strength tends to increase.

Relative Strength of Concrete from Cubes of Different Sizes

Cub size (mm)	100	150	200	300
Relative strength to 150mm cubes	1.05	1.0	0.95	0.87

2. Stress situation

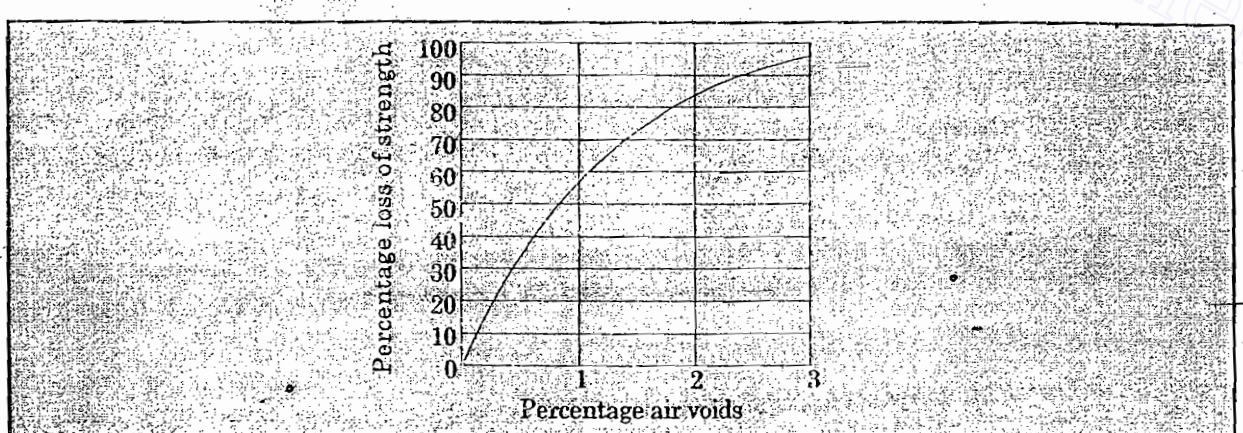
- Concrete under triaxial state offers more resistance and fails only after considerable deformations giving higher crushing strength than the actual, which justifies uniaxial compression testing and the use of cylindrical specimen.

3. Moisture condition of specimen

- Dry cubes may have drying shrinkage and bond failure leading to smaller strength. Moisture content in concrete provides lubrication effect and reduces the strength.
- Strength of dry sample = (1.1 to 1.2) × strength of saturated sample

4. Air Voids

- Strength of concrete decrease with the increase in percentage of air voids.
- Air voids are formed by evaporation of water used in making concrete and by entrained air.



Loss of Strength with the Percentage of Air-Voids

I.E.S MASTER
Institute for Engineers
IES/GATE/PSUs
Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
Phone: 011-41013406, 7838813406, 9711853908

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5. **Rate of loading**

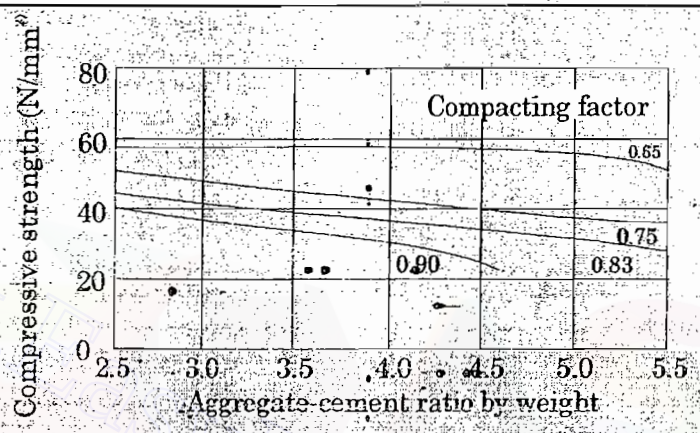
- Strength of concrete increases with the increase in rate of loading.
- At low rates of loading there is more time for creep to occur, so that the increase of strength with rate of loading provides evidence for the theory that failure occurs at limiting values of strain, rather than stress.

6. **Age of Cement**

- As the cement ages, its strength reduces since it gets set by absorption of moisture.

7. **Cement aggregate ratio**

- Provided all the other factors kept constant and increasing cement to aggregate ratio ultimate strength will increase to some extent



Influence of Aggregate / Cement Ratio on the Strength of Concrete

8. **Type and size of aggregate**

- Aggregate shape affects the their packing and hence void content also.
- Reduction in the void content of the coarse aggregate by better packing, means that the amount of mortar can be reduced and hence sand and cement.
- If coarse aggregate to sand ratio is increased and although the overall mix may be leaner the mortar may be richer, and by virtue of reduction in water/cement ratio which may thereby be permitted, the strength of concrete may be increased.
- Rounded spherical or cubical shaped aggregate when compacted contains less voids than an irregular and flaky aggregate of the same nominal size and they give more strength.
- It is observed that high strength concrete gives lower strength as compared to lean concrete if large size aggregate is used.
- Generally it is believed that lager the maximum size of aggregate , denser and stronger will be concrete because large aggregates have lower total surface area and require lower water to cement ratio resulting in higher strength. But in reality larger aggregates give lower surface area for development of gel bonds which leads to low strength.

9. **Degree of Compaction**

- Inadequate compaction leading to air void contents of 5 per cent and of 10 per cent result in a loss of strength of 30 per cent and 60 per cent, respectively.

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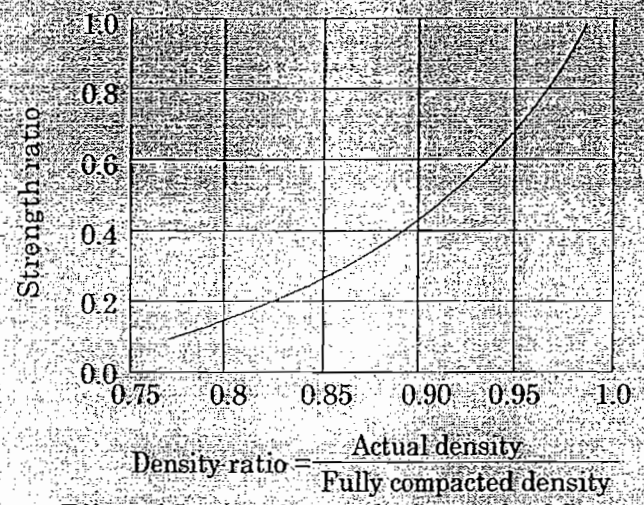

Effect of Compaction on the Strength of Concrete

WORKABILITY

- Workability is defined as the property of concrete which determines the amount of useful internal work necessary to produce full compaction.
- In simple words it can also be defined as the ease with which concrete can be compacted 100% with regard to mode of compaction and place of deposition.
- A concrete which can be readily compacted is said to be workable, but to merely say that workability determines the ease of placement and the resistance to segregation is too loose a description of this vital property of concrete.
- Desired workability in any particular case would depend on the means of compaction available; likewise, a workability suitable for mass concrete is not necessarily sufficient frothing, inaccessible, or heavily reinforced sections.
- It should be noted at workability is different from consistency. Consistency indicates fluidity or mobility.
- Concrete with high consistency may not be workable for a particular job and concrete having same consistency may vary in workability.

FACTORS AFFECTING WORKABILITY

1. **Water Content:**
   - Fluidity of concrete increases with water content because addition of water enhacne inter-partiele lubrication.
   - At site it is normal practice to increase the water content to make the concrete workable which lowers the strength.
   - In controlled concrete this cannot be resorted and even in uncontrolled concrete this should be the last choice.
   - But in case if more water is added due to any reason the cement content should be proportionately increased.
2. **Mix Proportions:**
   - Aggregate-cement ratio influences the workability to a large extent. The higher the ratio leaner will be the concrete. Lean concrete, paste available for lubrication of per unit surface area of aggregates will be less and hence the workability is reduced.

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3. **Aggregate Size:**
   - Big size aggregate the total surface area to be wetted is less, also less paste is required for lubricating the surface to reduce internal friction. For a given water content big size aggregate give high workability.

4. **Shape of Aggregates:**
   - At a given water content, round and cubical shape aggregates are more workable than rough, angular or flaky aggregates, because these type of aggregates requires less cement paste for lubrication as these have less surface area and lesser voids.
   - In round aggregates frictional resistance is small, so less lubrication is required. For this reason river sand and gravel provide greater workability than crushed sand and aggregates.

5. **Surface Texture:**
   - Rough surface aggregate will have more surface area than a smooth round textured aggre gate. Therefore smooth will be more workable

6. **Grading of Aggregates:**
   - Well graded aggregates are more workable. Because such a mix will have least voids and thus excess cement paste will be available as lubricant.

7. **Admixtures:**
   - Air entrained concrete is more workable. Because air forms bubbles, on which the aggre gates slide past each other increasing the workability.
   - Air entraining agents are surface active and they reduce the internal friction between the aggregates.

MEASUREMENT OF WORKABILITY

1. **Slump test**

- Slump test is one of most extensively used test all over the world.
- Slump test does not measure workability of concrete, although it gives a measure of consistency, but is very useful in detecting variations in uniformity of mix of given nominal proportions.
- Dimensions of the mould are, bottom diameter = 200 mm, top diameter = 100 mm, and height = 300 mm.
- Mould is filled in with fresh concrete in four layers, each layer of approximately one-quarter of the height of the mould and tamped with 25 strokes of the rounded end of the tamping rod (Dia = 16mm & length is 60 mm).
- Strokes are distributed in a uniform manner over the cross-section and for the second and subsequent layers should penetrate into the underlying layer.
- After the top layer has been rodded, the concrete is struck off level with a trowel or the tamping rod, such that the mould is exactly filled.
- Mould is removed immediately by raising it slowly and carefully in a vertical direction.
- It allows the concrete to subside and the slump is measured immediately by determining the difference between the height of the mould and that of the highest point of the specimen being tested.
- Slump measured is recorded in terms of millimeters of subsidence of the specimen.

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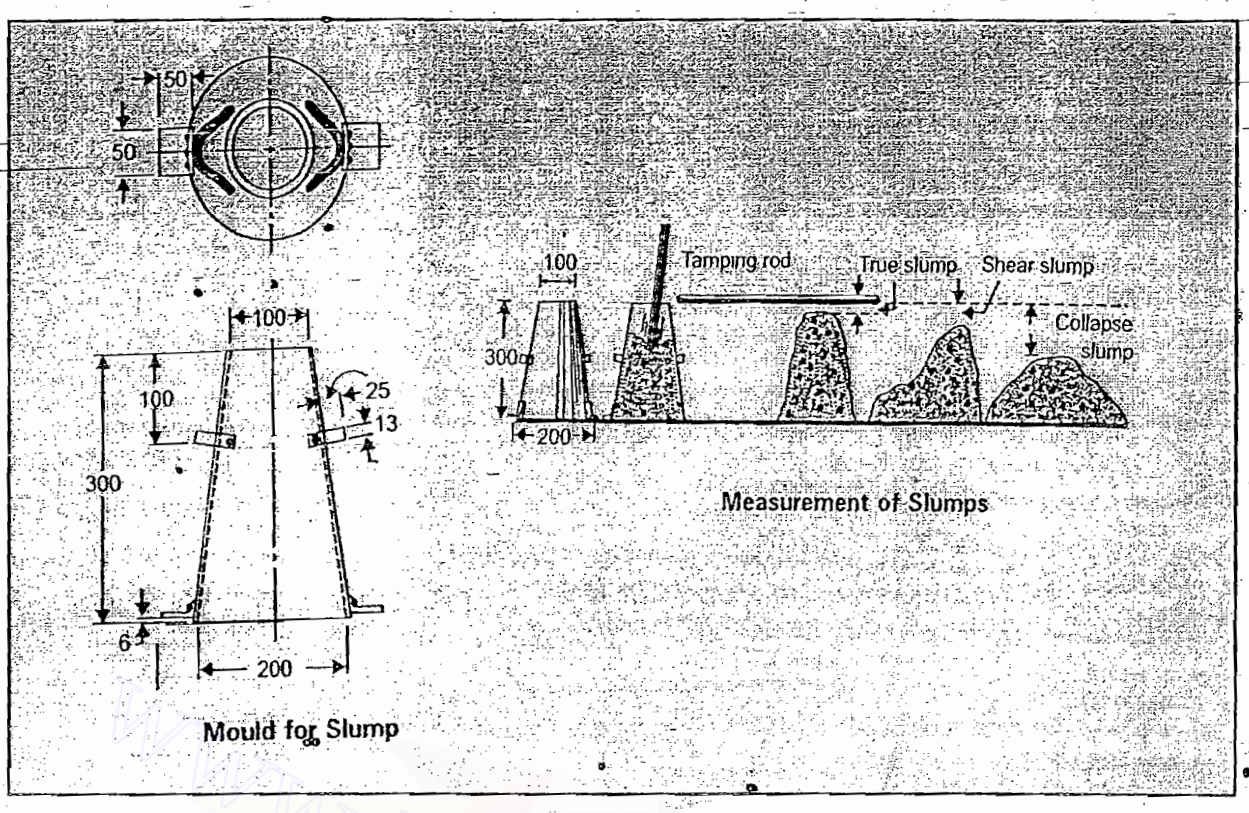

Note:

- Some indication of the cohesiveness and workability of the mix can be obtained, if after the slump measurement has been completed, the side of the concrete is tapped gently with the tamping rod; a well-proportioned concrete of an appreciable slump will gradually slump further, but if the mix has been badly proportioned, it is likely to fall apart.
- Test is performed with maximum size of aggregate as 38 mm only. But , if the aggregate size is larger the concrete is wet sieved through 38 mm screen to exclude aggregate particles bigger than 38mm.

No.	Types of Concrete	Slump(mm)
1.	Concrete for Road construction	20 to 40
2.	Parapets, piers, slab, beams	40 to 50
3.	Concrete for canal lining	70 to 80
4.	Concrete for arch and side wall of tunnel	90 to 100
5.	Normal R. C. Cwork	80 to 150
6.	Mass Concrete	25 to 50
7.	Concrete to be vibrated	10 to 25

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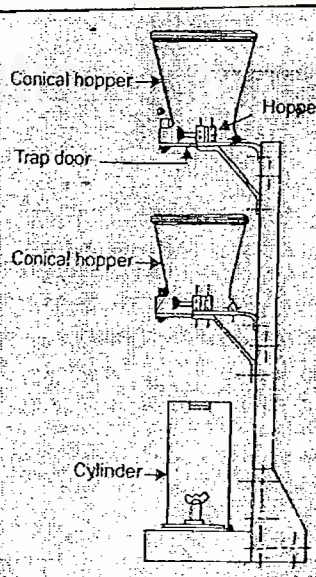
Values of Workability for Different Placing Conditions

Degree of Workability	Consistency	Slump (mm)	Compacting factor	Vee-Bee degree (sec)	Characteristics	Uses
Extremely Low	Moist Earth	0	0.65-0.7	> 20	Particles of coarse aggregate in the concrete are adheerve, but concrete does not clot, risk of segregation.	Precast paving slabs
Very Low	Very Dry	0-25	0.7-0.8	12-20	Concrete has the consistency of very stiff porridge, forms a stiff mound when dumped, and barely tends to shake or roll itself to form an almost horizontal surface when conveyed for a long time in, say, a wheel-barrow.	Roads (power vibrator)
Low	Dry	25-50	0.8-0.85	6-12	Concrete has the consistency of stiff porridge, forms a mound when dumped, and shakes or rolls itself to form a horizontal surface when conveyed for a long time in, say, a wheel-barrow.	Mass concreting, light reinforced section, roads (hand vibrator)
Medium	Plastic	50-100	0.85-0.95	3-6	Concrete can be shaped into a ball between the palms of the hands, and adheres to the skin.	Flat slabs, heavily reinforced section, RCC Sections (Manual Vibrator)
High	Semi-fluid	100-175	0.95-1	0-3	Concrete cannot be rolled into a ball between the plams of the hands, but spreads out even though slowly and without affecting the cohesion of the constituents so that segregation does not occur	RCC with congested reinforcement(can not be vibrated)

2. Compacting Factor test

- This test is more accurate and sensitive than the slump test especially for it is useful for concrete mixes of medium and low workabilities i.e. compacting factor of 0.9 to 0.8.
- Concrete of very low workability of the order of 0.7 or below, the test is not suitable, because this concrete cannot be fully compacted for comparison in the manner described in the test.
- The test should be made for concrete with maximum size of aggregate ≯ 40mm.
- It is primarly designed for laboratory work but can also be used in the field.



Compacting Factor Apparatus

J.E.S MASTER
Institute for Engineers
IES/GATE/PSUs
Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
Phone: 011-41013406, 7838813406, 9711853908

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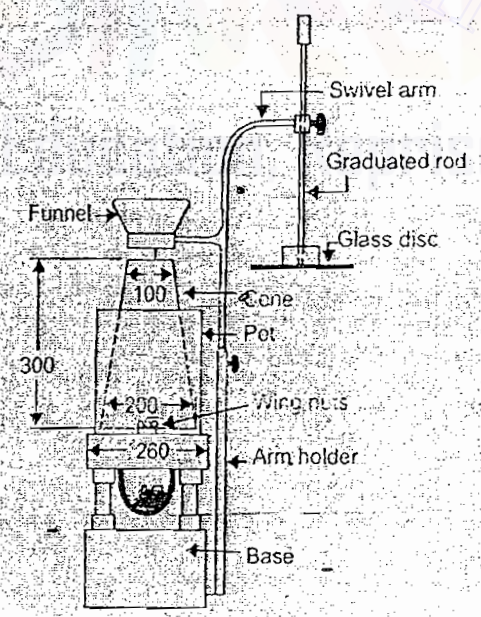
- Sample of concrete to be tested is placed gently in the upper hopper, and levelled
- Trap-door is then opened to allow the concrete to fall into the lower hopper.
- Sticked concrete in the upper hopper at sides is gently pushed into lower one.
- The trap-door of the lower hopper is opened so that the concrete falls in the cylinder.
- The excess of concrete remaining above the level of the top of the cylinder should be cut off and removed.
- As a rough guide the following relation between compacting factor and slump may be assumed

Compacting Factor	0.8	0.85	0.9	0.92	0.95
Slump (mm)	25	50	75	100	150

- Weight of the concrete in the cylinder is then determined to the nearest 10 gm this is known as wt of partially compacted concrete.
- Cylinder is refilled with concrete from the same sample in layers of 50 mm deep, each layer being heavily rammed or preferably vibrated so as to obtain full compaction.
- Top surface of the fully compacted concrete is carefully struck off level with the top of the cylinder.
- The mass of concrete in the cylinder should be measured and it is known as the mass of fully compacted concrete.
- *Compacting factor is defined as ratio of the weight of partially compacted concrete to the weight of fully compacted concrete. i.e.* $C.F = \frac{\text{mass of partially compacted concrete}}{\text{mass of fully compacted concrete}}$
- CF = 0.85 low workability
  CF = 0.92 medium workability
  CF = 0.95 high workability

3. Vee-Bee Consistometer Method



Vee-Bee Consistometer

I.E.S MASTER
Institute for Engineers
IES/GATE/PSUs
Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
Phone: 011-41013406, 7838813406, 9711853908

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- This test determines the time required for transforming, by vibration, a concrete specimen in the shape of a conical frustum into a cylinder.
- Apparatus consists of a vibrator table resting upon elastic supports, a metal pot, a sheet metal cone, open at both ends, and a standard iron rod.
- Slump test is performed in the cylindrical pot of the consistometer which is a good laboratory test to measure indirectly the workability of concrete.
- Glass disc attached to the swivel arm is moved and placed just on the top of the slump cone in the pot and before the cone is lifted up, the position of the concrete cone is noted by adjusting the glass disc attached to the swivel arm.
- Cone is then lifted up and the slump noted on the graduated rod by lowering the glass disc on top of the concrete cone.
- Electrical vibrator is switched on and the concrete is allowed to spread out in the pot.
- Vibration is continued until the whole concrete surface uniformly adheres to the glass disc and the time taken for this to be attained is noted.
- Consistency of the concrete is expressed in VB degree which is equal to the recorded time in seconds.

MIX DESIGN

- Design of concrete mix involves economical selection of relative proportion of various ingredients of concrete.
- Apart from meeting the criteria of strength, it is desired that concrete must be workable in fresh state and impermeable and durable in hardened state.
- Several methods of mix design has been developed over the years in many countries.
- In India, we follow IS: 10262–1982 and SP23–1982 for recommendations and guidance of mix design.

Steps

1. Determine target mean strength (f_{cm}) from the desired characteristic strength (f_{ck}).

$$f_{cm} = f_{ck} + 1.65\sigma$$

were,

f_{cm} = target mean strength

f_{ck} = characteristic strength required.

σ = standard deviation, which is calculated from previous record or obtained from code (IS:456) as per the table below.

Grade of concrete	Assumed σ
$M_{10} - M_{15}$	3.5
$M_{20} - M_{25}$	4.0
$M_{30} - M_{50}$	5.0

2. Determine the *water-cement ratio*, based on the 28-day strength of cement and the mean target strength of concrete. This ratio should not exceed the limits specified in Table below (for durability considerations).

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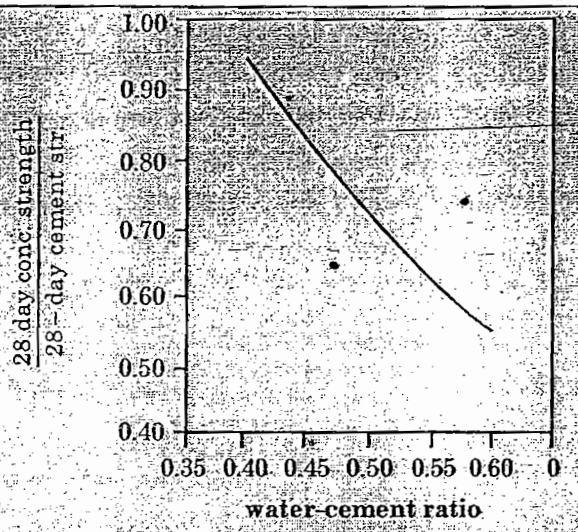

Relation between water-cement ratio and compressive strength.

Exposure conditions and requirements for RC work with normal aggregate (20 mm nominal size)

Exposure Category	Description	Min. grade (kg/m³)	Min. Cement ratio	Max. free w/c
Mild	Protected against weather or aggressive-conditions, except if located in coastal area.	M 20	300	0.55
Moderate	Sheltered from severe rain or freezing whilst wet, or Exposed to condensation and rain, or Continuously under water, or In contact with or buried under non-aggressive soil or ground water, or Sheltered from saturated 'salt air' in coastal area	M 25	300	0.50
Severe	Exposed to severe rain, alternate wetting and drying or occasional freezing whilst wet or severe condensation, or Completely immersed in sea water, or Exposed to coastal environment	M 30	320	0.45
Very Severe	Exposed to sea water spray, corrosive fumes or severe freezing whilst wet, or In contact with or buried under aggressive subsoil or ground water	M 35	340	0.45
Extreme	Members in tidal zone, or Members in direct contact with liquid / solid aggressive chemicals	M 40	360	0.40

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3. Determine the water-content V_w based on workability requirements, and select the ratio of fine aggregate to coarse aggregate (by mass), based on the type and grading of the aggregate the former is generally in the range of 180-200 lit/m³ (unless admixtures employed), and the latter is generally 1:2 or in the range of 1:1½ to 1:2½.

4. Calculate the cement content M_C (in kg/m³) by dividing the water content by the water-cement ratio, and ensure that the cement content is not less than that specified in the above table for durability considerations. Also calculate the masses of fine aggregate M_{fa} and coarse aggregate M_{ca} based on the absolute volume principle:

$$\frac{M_C}{\rho_C} + \frac{M_{fa}}{\rho_{fa}} + \frac{M_{Ca}}{\rho_{Ca}} + V_w + V_V = 1.0$$

where ρ_C, ρ_{fa}, ρ_{Ca} denote the mass densities of cement, find aggregate and coarse aggregate respectively, and V_v and V_w denote respectively the volumes of voids (approx. 2 percent) and water per cubic meter of concrete.

5. Determine the weight of ingredients per batch, based on the capacity of the concrete mixer.

DURABILITY

- If concrete is to serve the purpose for which it is designed during its intended lifetime, it has to be durable.
- Therefore a durable concrete is one that performs satisfactorily under anticipated exposure conditions for stipulated life of the structure.
- Loss in durability results in reduced life of the structure and this loss can be divided in to two groups i.e external factors and internal factors.
- External factors pertain to the type of environment to which the concrete is exposed, whereas the internal factors pertain to characteristics inherent to the built concrete.

Various factors affecting durability of concrete are as follows.

1. **Permeability**

- We can say that almost all forms of detoriation in concrete is due to ingress of water as it leads concrete susceptible to chemical attack, forst action, rusting of steel etc.
- As ingressing of water is mainly depending on permeability of concrete therefore to cease detoriation permeability has to be reduced.
- We can reduce permeability by
  - (i) Providing high grade of concrete
  - (ii) Using well-graded, dense aggregate
  - (iii) Using low water-cement ratio, adequate cement and effective curing.
  - (iv) Using appropriate admixtures (including silica fume)
  - (v) Achieving maximum compaction
  - (vi) Taking care while designing to minimise possible cracks

2. **Frost Action**

- Concrete is be affected due to being permeable or by temperature below 0°C.
- Because of expansion of absorbed water on freezing.
- Ice builds up in large pores causing large expansion in local areas the others being dry cause disintegration.

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- Conditions favoring frost attack are
  - (i) Horizontal surfaces open to sky absorbing more water in wet conditions and cooling quicker by radiation.
  - (ii) Low temperatures increasing the extent of migration of water resulting in freezing to greater depths in the concrete.

3. **Sulphate attack**

- Sulphate attack is a chemical reaction between the products of hydration of cement and solution containing sulphate of calcium, Magnesium and sodium.
- These sulphates reacts with C_3A and formed calcium sulphate and calcium sulphoaluminate (ettringite) which expands and causes disruption of concrete.
- Common source of sulphate salts is the soil around the concrete foundation, from the water used in making concrete, and by using unwashed aggregates.
- It can be reduced by use of blast furnace slag cement, sulphate resisting cement, supersulphated cement, and by reducing the permeability.

4. **Mineral Oils**

- Pertroleum and its products do not directly affect hardened concrete.

5. **Organic Acids**

- Acetic acid, lactic acid, and butyric acid severally attack concrete.
- Formic acid is corrosive to concrete.

6. **Sugar**

- It is a retarding agent and gradually corrodes concrete. Can be reduced by surface with sodium silicate solution, tar or asphalt.

7. **Sewage**

- H_2S gas evolved from septic sewage promotes, the formation of H_2SO_4 affecting the concrete. However, sewers running full are not affected.

DEFECTS

1. **Cracks**

- Cracks are inherent in concrete and cannot be completely prevented but can be minimized.
- Use of unsound materials, high w/c ratio, bad jointing techniques, freezing, thermal effects, etc. lead to cracks and make the concrete less durable.
- Acceptable limits the surface width of cracks is 0.1 to 0.3mm.
- **Excess Water :** Water in excess of the requirement causes coarse aggregate to settle more and the water bleeds to top and evaporate leaving voids. This porous, weak concrete will be unable to bear shrinkage stresses without cracking. Concrete may also shrink down in the forms in the cases of beams and walls.
- **Early Loss of Water :** results in shrinkage cracks during or soon after the finishing because of moisture absorption by dry subgrade, dry forms, dry aggregates or hot sunny weather.
- **Alkali Aggregate Reaction :** Aggregates containing reactive silica are prone to reaction with alkalis (Na_2O & K_2O) in cement paste.

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- The reaction, however, is possible only in the presence of high m/c with in the concrete and leads to expansion, cracking and disruption of concrete.
- **Steel :** The corrosion of steel bars may cause cracks and rust stains to appear in the concrete.
- **Freeze and Thaw:** cracks because of freeze and thaw are normally observed in concrete with high w/c ratio, producing tiny crevices and voids around the aggregates, allowing the rain water to penetrate into concrete.

2. **Crazing**

- It development of a network of fine random cracks or fissures on the surface of concrete or mortar caused by shrinkage of surface layer.
- Cracks rarely exceed 12 mm or so in depth, and are therefore not serious, apart from the unsightliness.
- Best method to overcome crazing is to be either to use an earthmoist mix, or if a plastic mix is necessary use as low a w/c ratio as is practicable and remove the cement skin to expose the aggregate.

3. **Efforescence**

- It is appearance of fluffy white patches on the surface of concrete members.
- And is caused by poorly washed aggregate, salty water used in making concrete the salts being leaching out to the surface by rain water afterwards. This can be controlled to some extent by coating the surface by a water repellent.

4. **Segregation**

- It is separation of (a) coarse aggregate from fine aggregate, (b) paste from coarse aggregate, or water from the mix and the ingredients of the fresh concrete no longer remain uniformly distributed.
- It can be reduced by increasing small size coarse aggregate, air entrainment, using dispersing agents and puzzolona.
- Causes of segregation are dropping concrete from heights, badly designed mixes, concrete carried over long distances—pumping, belt conveyor system etc, over vibrations, and during concrete finishing extra floating and tamping.

5. **Bleeding**

- It is an autogenous flow of mixing water within or emergence to the surface from freshly placed concrete is usually due to excessive vibrations imparted to concrete to achieve full compaction.
- Bleeding can be reduced by the use of uniformly graded aggregates, puzzolona—by breaking the continuous water channel, or by using—entraining agents, finer cement, alkali cement, and a rich mix.
- The excess water along with cement comes to the surface by capillary action and this cement water mixer form a scum or thin layer of chalky material known as laitance.

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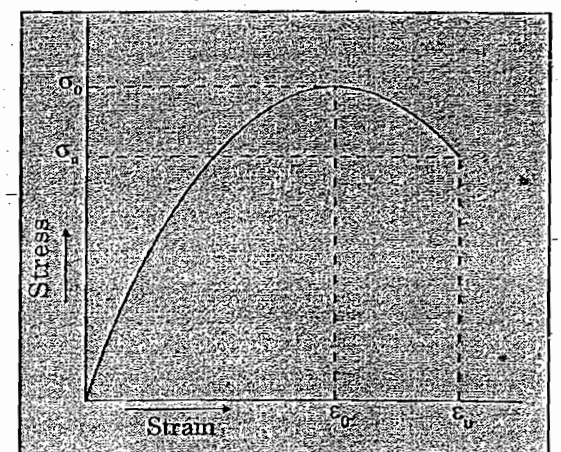
Physical Proportions of concrete

1. Stress strain curve

- Stress strain curve of concrete in compression is as below
- Since mortar and concrete have no elastic limit, the modulus of elasticity for concrete must be the slope of the stress deformation curve at zero stress.
- Elastic modulus of concrete in compression, $E_c = 5000\sqrt{f_{ck}}$, where f_{ck} is the characteristic strength of concrete.
- Elastic modulus of concrete varies from 14 × 10^3 to 40 × 10^3 N/mm^2. and increases with the density and to some extent with age.



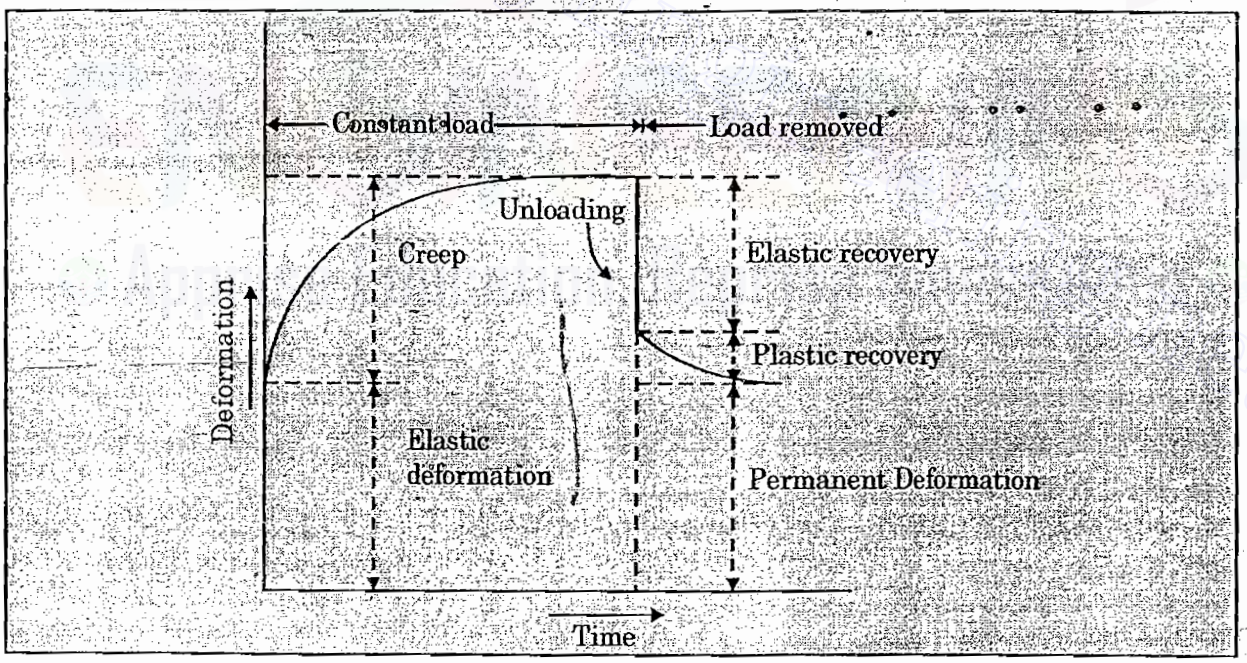
Stress-Strain Curve for Concrete

2. Poison's ratio

- It is determined as the ratio of lateral to longitudinal strain in compression test and vary from 0.1 to 0.3, but for dynamic tests its value is slightly high i.e. 0.24.

3. Creep

- It is continued deformation with time under a constant load , it is also known as plastic flow or time yield.
- Rate of creep decrease with time and the creep strains at five years are taken as terminal values. It increases rapidly with the stress, loading at an early age of concrete, broken ballast, soft and porous aggregate, poorly graded and improperly compacted concrete.



- Creep may be due to closer of internal voids, viscous flow of the cement paste and flow of water out of the cement gel. Creep causes large deformations and deflections and is undesirable.

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In general Creep increases when

- Cement-content is high
- Water-cement ratio is high
- Aggregate content is low
- Air entrainment is high
- Relative humidity is low
- Temperature (causing moisture loss) is high
- Loading occurs at on early age and
- Loading is sustained over a long period

NON DESTRUCTIVE TESTING

- The tests described so far in this chapter involve specially made specimens which, as such, do not necessarily give direct information about the concrete in the actual structure; yet, this is what matters.
- Field -cured test specimens, and also cores, are of some help in this respect. But these require pre-planning, and the latter cause damagealbe it local, to the structure.
- To solve these problems, a wide range of in-situ tests, known also as in-place tests, have been developed.
- These tests are traditionally called nondestructive tests, it being understood that some minor damage to the structure may be involved, although its performance or appearance must not be impaired.
- An important feature of nondestructive tests is that they permit retesting at the same, or nearly the same, location so that changes with time can be monitored.
- Use of nondestructive tests leads to increased safety and allows better scheduling of construction, thus making it possible to progress faster and more economically.
- These tests can be categorized into those that assess the strength of the concrete in situ, and those that determine other characteristics of the concrete, such as voids, flaws, cracks, and deterioration.
- Nondestructive methods are quick and can be performed both in laboratory and in-situ with convenience.
- Nondestructive test (NDT) can be performed on fresh (green) as well as hardened concrete with equal ease and are described as follows.

NDT TEST ON FRESH CONCRETE

- On fresh concrete maturity test and ultrasonic test can be done as NDT test.

Maturity test

- It is based on the principle that concretes having equal maturities will have equal compressive strengths, regardless of temperature and curing histories
- Maturity of the in-situ concrete at the early ages can be determined with the aid of an instrument known as maturity meter. Used to determine the earliest safe time for removal of formwork.
- Results are authentic provided the concretes have initial temperature between 15-26°C and there is no loss of moisture during the period of curing.

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Ultrasonic Pulse Velocity Test

- This test is based on the principle that velocity of sound in a solid material is a function of $\sqrt{\frac{E}{\rho}}$ where E is modulus of elasticity and ρ is density.
- An ultrasonic pulse apparatus consists of a transmitter and a reciever which are held against two faces of concrete.
- The apparatus generate pulse of ultrasonic frequency which are transmitted through concrete by the transmitter.
- On the other face, the receiver receives the pulse and the apparatus record them.
- The velocity of the pulse is found which is correlated to the strength of the concrete.
- Higher the velocity of pulse, greater the strength of concrete.
- At present the ultrasonic pulse velocity method is the only one of dynamic test type that shows potential concrete strength in-situ.
- Pulse velocity tests can be carried out on both laboratory-sized specimens as well as on completed concrete structures.
- Some of the factors that affect measurements are as below.
  1. Path-lengths to be at least 30 cm in order to avoid any errors introduced by heterogeneity.
  2. It must be considered that there is an increase in pulse velocity at below-freezing temperature owing to freezing of water; between 5 to 30°C pulse velocities are not temperature dependent.
  3. Presence of reinforcing steel in concrete has an appreciable effect on pulse velocity. It is, therefore, mandatory to choose pulse paths that avoid the influence of reinforcing steel or to make corrections if steel is in the pulse path.

NDT TEST ON HARDENED CONCRETE

Pull-out-test

- This is a test which measures, by means of a special tension jack, the force required to pull out a previously cast-in metal insert with an enlarged end.
- The insert is pulled out with a lump of concrete, approximately in the shape of a frustum of a cone.
- This shape is the consequence of the geometry of the insert together with the bearing ring. For a given geometry , the pullout force is related to the compressive strength of concrete.
- This relation is purely experimental, and not based on consideration of stresses involved, because the stress system at the fracture surface is three-dimensional: there are radial and circumferential tensile stresses, and a compressive stress along the surface of the cone.

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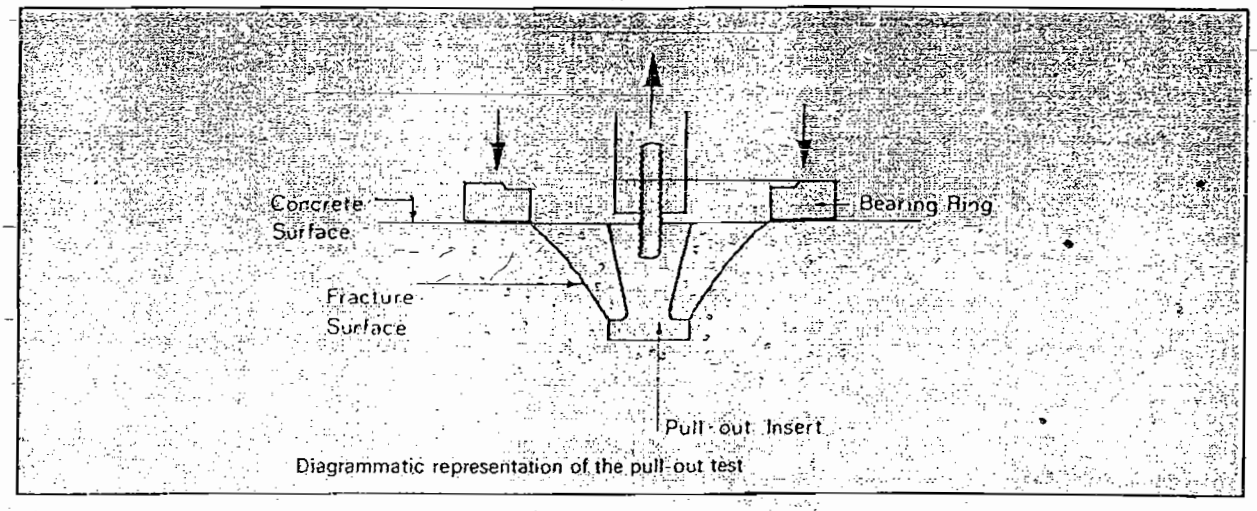

Diagrammatic representation of the pull-out test

Limitations

- They have to be planned in advance and pull out assemblies are to be set in the form work before the concrete is placed.

Advantages

- They measure qualitative strength of concrete in place.

Penetration test

- The determination of the resistance of concrete to penetration by a steel rod, or probe, driven by a fixed amount of energy can be used to assess the compressive strength of concrete.
- For standard test conditions, the depth of penetration is inversely proportional to the compressive strength of concrete, but no theoretical basis for this has been established.
- The Windsor probe is generally considered to be the best means of testing penetration. It consists of powder-actuated gun or driver, hardened alloy probes, loaded cartridges, a depth gauge for measuring penetration of probes and other related equipment.
- 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. Calibration charts are provided by the manufacturer, the instrument should be calibrated for type of concrete and type and size of aggregate used.

Limitation

- It gives quite variable results and should not be expected to give accurate value of concrete strength.
- It is very expensive test.

Advantages

- It has, the potential for providing a quick means of checking quality and maturity of in-situ concrete. It also provides a means of assessing strength development with curing.

Ultra-Sonic test

- Ultrasonic pulse velocity method as described for green concrete can also be used to determine the strength of hardened concrete.
- Flaws, quality of concrete, reinforcement, moisture-content, temperature of concrete materials, etc. affect the pulse velocity and suitable adjustments should be made in evaluating the concrete strength.

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Advantages

- If can be used for existing structures and those under construction.
- Pulse velocity reading are indicative of good quality concrete.

Quality of Concrete and Pulse Velocity

General Condition	Pulse Velocity m/sec
Excellent	Above 5000
Good	4000-5000
Questionable	3000-4000
Poor	2000-3000
Very poor	below-2000

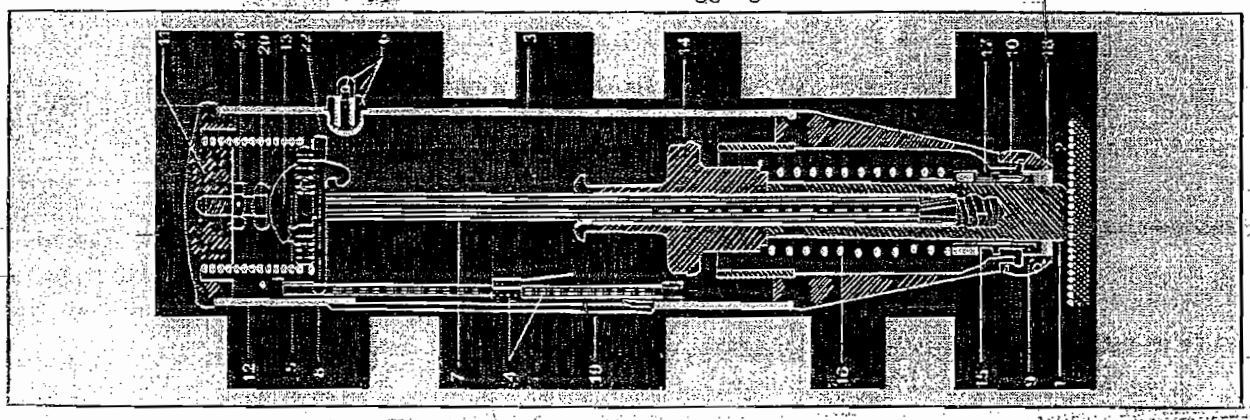
- Fairly good correlation can be obtained between cube compressive strength and pulse velocity.
- Cracks on concrete can also be detected.

Disadvantages

- Holes have to be cut in the formwork so that transducers can be in direct contact with the concrete surface.
- As concrete ages, the rate of increase of pulse velocity slows down much more rapidly than the rate of development of strength.
- Accuracy depends on careful calibration as well as on the use of the same concrete mix proportions and aggregate in making the test samples used for calibration as in the structure.

Rebound Hammer Test (Schmidt hammer Test)

- It is a surface hardness tester for which an empirical correlation has been established between strength and rebound number.
- It is based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges.
- For this test, a rebound hammer also called Schmidt hammer, which weighs about 1.8 kg and is suitable for both laboratory and field work.
- It has a spring-controlled hammer mass that slides on plunger within a tubular casing.
- Hammer is forced against the surface of the concrete by the spring and the distance of rebound is measured on a scale which give indication of concrete strength.
- This test is suitable for the concrete having strength in the range of 20–26 MPa.
- Results are affected by factors such as smoothness of surface, size and shape of specimen, moisture condition of the concrete, type of cement and coarse aggregate and extent of carbonation of surface.



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Maturity Test

- Basic principle of concrete maturity is that increase in strength is a function of time and temperature, and that any standard of maturity in terms of strength must include both temperature and period of curing.
- It must be noted that in measuring maturity no property of the concrete itself is measured.
- It will not indicate the quality of the concrete.

Radioactive Methods

- Concrete absorbs X-rays and γ-rays passing through it and the degree of absorption depends on the density of concrete.
- Such rays, while passing through concrete, are partly absorbed and partly scattered.
- Scattered radiation can be shielded from the measuring device and the density of concrete determined by the degree of absorption of the rays traversing a direct path of known length.
- Radium and radio-cobalt are used as source of rays. Radium has the advantage that its activity can be regarded as constant since it takes 1000 to 2000 years for its activity to be reduced by half but radio-cobalt whose activity reduces to half in just five years is preferred because it is quite cheap.
- Radioactive methods of testing concrete can be used to detect the location of reinforcement, measure density and perhaps establish whether honeycombing has occurred in structural concrete units.
- Equipment is quite simple and running costs are small, although the initial price can be high as X-rays involve very high voltages and make use of very expensive equipments restricting their use in field.
- Concrete up to 45 cm thick can be examined without any difficulty.
- Maximum thickness of concrete which -rays can penetrate is 90 cm and in field practically it is 60 cm only. γ-rays, produced by radio active materials, are highly penetrative and are therefore preferred.

NEED OF NON-DESTRUCTIVE TESTING

- For new concrete structures under construction, N.D.T. may be required under following circumstances:
  1. Non-compliance of the material supplied in terms of works specimen test results or other specified requirements.
  2. Uncertainties concerning the level of workmanship involved in construction operations affecting the hardened properties of the in-situ concrete.
  3. Quality control of construction.
  4. Monitoring of strength development in relation to formwork removal, curing, prestressing, load application or similar purposes.
- Existing concrete structure require an examination under the following circumstances:
  1. Deterioration of the concrete due to factors such a external or internal chemical attack, fire explosion and other environmental effects.
  2. To make assessment of the load carrying capacity of an existing structure for change of ownership or insurance purpose or in relation to a proposed change of use or alteration.

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ADVANTAGES OF NON-DESTRUCTIVE TESTING

- Non-destructive methods have following distinct advantages over destructive methods of testing.
  1. The measurement can be done on concrete in-situ and thus representative samples are not required.
  2. Non-destructive testing makes its possible to study the variation in quality of concrete with time and external influences.
  3. N.D.T. method the concrete is not loaded to destruction. Its quality is judged by measuring certain of its physical properties, which are related to its quality.
  4. N.D.T. there is no wastage of material as in destructive methods of testing.

RHEOLOGY

- Rheology is science of flow and deformation of matter and describes one interrelation between force, deformation and time.
- Rheological principles and techniqtues as applied to concrete include the deformation of hardened concrete, handling and placing of freshly mixed concrete and the behaviour of its constituent parts, namely cement slurries and pastes.
- Rheology of fresh concrete like workability includes the parameters of stability, mobility and compatibility.
- Mechanical behaviour of hardened cement paste, which exhibits both elastic and inelastic deformations, can be expressed in rheological terms

Factors Affecting Rheological Properties

1. **Mix Proportions.**

- Concrete mix having an excess amount of coarse aggregate will lack sufficient mortar to fill the void system, resulting in a loss of cohesion and mobility.
- Such a mix is termed harsh and requires a great amount of effort to place and compact.
- Whereas an excessive amount of fine aggregate or entrained air in a concrete mixture will greatly increase the cohesion and render the concrete difficult to move.

2. **Consistency.**

- Consistency of concrete measured by the slump test is an indicator of the relative water content in the concrete mix.
- An increase in the water content or slump above that required to achieve a workable mix produces greater fluidity and decreased internal friction.

3. **Hardening and stiffening.**

- High temperature, rapid hardening cement, and use of accelerating admixtures, increase the rate of hardening which will decrease the mobility of concrete.

4. **Aggregate shape and texture.**

- Rough and highly angular aggregate particles will cause a high percentage of voids filled by mortar, requiring higher fine aggregate contents and correspondingly higher water content.
- Similarly an angular fine aggregate will increase internal friction in the concrete mixture and require higher water content than well rounded natural sands.

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5. **Aggregate grading.**

- Well graded aggregate gives good workability whereas Gap graded aggregate affects void and workability.

6. **Maximum size of aggregate.**

- Increase in the maximum size of aggregate will reduce the fine aggregate requirement to maintain a given workability and will thereby reduce the surface area to be wetted and hence the cement content necessary for a constant water-cement ratio.

7. **Admixtures.**

- Admixtures having significant effect on the rheology of concrete are plasticizers and super-plasticizers, air-entraining agents, accelerators and retarders.
- Lignosulfonate salt based plasticizers (0.15%) reduce the water content by 10% without any detrimental effect.
- Super-plasticizers and plasticizers prevent the formation of flocculated structure by changing the interparticle attracting / repulsion.
- air-entraining agents introduce spherical air bubbles 10 to 25 mm to diameter by modifying the surface tension of the aqueous phase in the mix.
- Bubbles act like ball bearings to allow larger particles to flow past each other more easily thus decreasing plastic viscosity.

SPECIAL CEMENT CONCRETES

Fiber Reinforced Concrete (FRC)

- Concrete containing a hydraulic cement, water, fine or fine and coarse aggregate, and discontinuous discrete fibers is called fiber-reinforced concrete (FRC).
- It may also contain pozzolans and other admixtures commonly used in conventional concrete.
- Fibers of various shapes and sizes produced from steel, plastic, glass, and natural materials are being used; however, for most structural and nonstructural purposes, steel fiber is the most commonly used.
- There is considerable improvement in the post-cracking behavior of concretes containing fibers. Although in the fiber-reinforced concrete the ultimate tensile strengths do not increase appreciably, the tensile strains at rupture do.
- Compared to plain concrete, fibre-reinforced concrete is much tougher and more resistant to impact.
- Plain concrete fails suddenly once the deflection corresponding to the ultimate flexural strength is exceeded; on the other hand, fiber-reinforced concrete continue to sustain considerable loads even at deflections considerably in excess of the fracture deflection of the plain concrete.
- Concrete mixtures containing fibers posses very low consistencies; however, the placeability and compactability of concrete is much better.
- Areas of Application of FRC materials are : pipes, panels, curtain walls, Slabs on grade, precast elements, Composite decks, Vaults, safes., Impact resisting structures

Light Weight or Foam Concrete.

- It is manufactured by using foaming or air entraining agents with slurry of cement and light weight sands.

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- These foaming agents form a large number of minute air bubbles dispersed in the concrete mass and makes it light.
- It is obtained by using different aggregates (sintered pulverized fuel ash (fly ash), pumice, volcanic tuff etc.) and varying proportions of foaming agents suitable for specific purposes.
- These concretes possess low thermal conductivity, low coefficient of thermal expansion and greater fire resistance and can be used for light weight roofs, false ceilings, light weight partition walls, etc.

Aerated Concrete.

- It is manufactured from calcarious and silicious materials like cement, lime, pulverized sand, flyash etc. by entrapping air cells.
- These entrapped air cells make the material light, impervious and a good insulator of heat.
- This concrete can be used for precast or cast in situ construction and can be produced in varying densities.

Heavy Weight Concretes.

- It can be produced by using specially heavy weight aggregates and compacting well by mechanical means.
- These concretes can be suitably used for gravity dams, retaining wall constructions, or special atomic power plant vessels, etc.

Pre-packed Concrete Construction.

- It is obtained by injecting cement-sand mortar under pressure to fill voids of already packed and fully compacted coarse aggregate.
- This concrete is quite dense and has very small shrinkage.

ADMIXTURES

- Admixtures are additives which are added to concrete mix at the mixing stage to modify the properties of concrete in its fresh and hardened state.
- It is either chemical (liquid) or 'mineral' (fine granular).
- Admixtures should never be regarded as a substitute for good mix design, good workmanship, or use of good materials.

Uses of admixtures

- Most common reasons for using admixtures in concrete are:
  - (a) To increase workability without changing water content.
  - (b) To reduce water content without changing workability.
  - (c) To effect a combination of the above.
  - (d) To decrease the density of concrete.
  - (e) To reduce segregation and/or bleeding.
  - (f) To improve pumpability.
  - (g) To accelerate the initial set of concrete i.e. to speed up the rate of strength development at early ages and also increase the strength.
  - (h) To improve potential durability and reduce permeability.
  - (i) To increase the resistance to chemical attack hence inhibits the corrosion of concrete.

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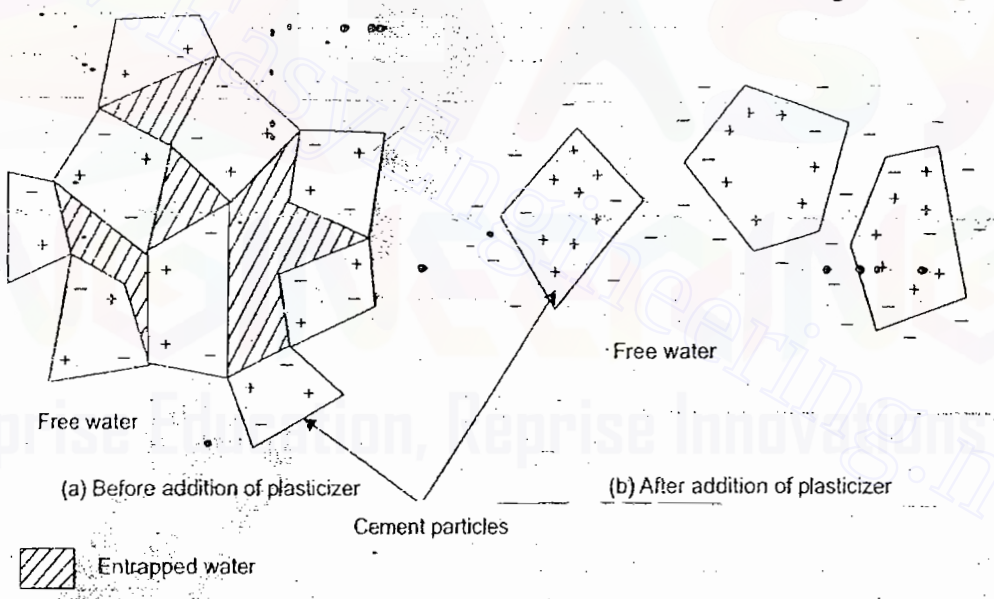
TYPES OF ADMIXTURES

- Admixtures are normally categorized according to their effect:
  - (a) Plasticizers (water-reducing agents)
  - (b) Superplasticizers (high range water reducers)
  - (c) Air entrainers
  - (d) Accelerators
  - (e) Retarders
  - (f) Others
- Many admixtures provide combinations of properties such as plasticizer/retarders or plasticizer/air entrainers. Each admixture type is discussed in the following sections.

Plasticizers

- Chemicals to improve plasticity in the fresh concrete; for improving workability (for a given w/c ratio) to facilitate placement of concrete in location that are not easily accessible; or these are mainly used for achieving higher strength by reducing the water-cement ratio.
- Main types of plasticizers are *lignosulphonic* acids and their salts, (e.g. Ca, Na, NH_4 salts) *hydroxylated carboxylic acids* and their salts, and modifications of both.
- The typical dosage of a plasticizer varies from 200 ml to 450 ml per 100 kg of cementitious material.



Disperse Mechanism of Cement Particles in Concrete before and after Addition of Plasticizers

- When plasticizers are added they get adsorbed on the cement particles.
- The adsorption of charged polymer on the cement particles creates repulsive forces b/w particles. This repulsive force is called zeta potential which depends upon the quantity of plasticizer used.
- In the dispersed state due to presence of water in between cement particles the inter particle friction is reduced.
- The adsorbed plasticizer on the surface of cement inhibits the surface hydration of cement as long as sufficient plasticizer are available.
- Plasticizer decreases as the polymers get entrapped in hydration products.

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Uses

- Plasticizers usually increase the slump of concrete with a given water content.
- Plasticizers can reduce the water requirement of a concrete mix for a given workability, as a rule-of-thumb, by about 10%.

Superplasticizers

- These admixtures are chemically distinct from normal plasticizers and although their action is basically the same, it is more marked.
- When they are used to produce flowing concrete a rapid loss of workability can be expected and therefore they should be added just prior to placing.
- Among the cement constituents C_3A exerts major influence on the properties of super-plasticizer.
- Finer the cement higher the super-plasticizer dose.
- Examples are *sulphonated melamine formaldehyde condensates, naphthalene sulphonate formaldehyde condensates, modified lignosulphonate* (MLS), and mixture of *saccharates and acid amines.*
- Higher is the molecular mass higher is the efficiency of super-plasticizer.
- It is capable of reducing water requirement by 20 to 40%.

Air entrainers

- An air-entraining agent introduces air in the form of minute bubbles that occupy upto 5% of the volume of concrete distributed uniformly throughout the cement paste. The main types include salts of wood resins, animal or vegetable fats and oils and sulphonated hydrocarbons.
- Following are some of the examples of air entraining agents :
  1. Natural wood resins and their soaps, of which vinsol resin is the best.
  2. Animal or vegetable fats and oils such as tallow or olive oil and their fatty acids such as stearic acid and oleic acids and their soaps.
  3. Wetting agents such as alkali salts of sulphonated or sulphated organic compounds.
- Air entrainment may reduce the strength of concrete and overdosing can cause major loss of strength.
- 1% air may cause a strength loss of 5%.
- The use of ground granulated blastfurnace slag (GGBS) and fly ash (FA) tends to reduce the amount of air entrained.

Uses

- Where improved resistance of hardened concrete to damage from freezing and thawing is required.
- For improved workability, especially in harsh or lean mixes.
- To reduce bleeding and segregation, especially when a mix lacks fines.

Accelerators

- These admixtures (notably, calcium chloride) speed up the chemical reaction of the cement and water and so accelerate the rate of setting and/or early gain in strength of concrete.
- Accelerator calcium chloride ($CaCl_2$) can be used in amounts up to 2% by mass of cement but code recommends upto 1.5% for reinforced concrete work in cold weater condition.
- The less commonly used accelerators consist of NaCl, Na_2SO_4, NaOH, Na_2CO_3, K_2SO_4 and KOH.
- The 2% $CaCl_2$ has the same effect on the acceleration of hydration as a rise in temperature of about 11°C.

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Uses

- Where rapid setting and high early strengths are required (e.g. in shaft sinking).
- Where rapid turnover of moulds or formwork is required.

Practical considerations

- All chloride-based accelerators promote corrosion of reinforcing steel and should not be used in:
- reinforced concrete
- water-retaining structures
- prestressed concrete
- steam-cured concrete
- Overdosing with these materials can cause instant setting of the concrete resulting in equipment damage.
- Accelerators work more effectively at lower ambient temperatures.

Retarders

- These admixtures slow or prolong the chemical reaction of the cement and water leading to longer setting times and slower initial strength gain.
- The most common retarders are hydroxylated carboxylic acids, lignins, sugar and some phosphates.

Uses

- When placing concrete in hot weather, particularly when the concrete is pumped.
- To prevent cold joints due to duration of placing.
- In concrete which has to be transported for a long time.

Practical considerations

- If a mix is overdosed beyond the limit recommended by the supplier, retardation can last for days.
- Retarders often increase plastic shrinkage and plastic settlement cracking.
- Delayed addition of retarders can result in extended retardation.

Note : Some substances may act as accelerators or as retarders according to the proportion added. For example, $CaCl_2$ when added upto 2 percent by weight of cement acts as accelerator, but on increasing the proportion, it acts as retarder and leads to flash set.

Water Proofer

- Cement mortar or concrete should be impervious to water under pressure and also should have sufficient resistance to absorption of water.
- Concrete can be made water resistant with the additives which may be water repellent type or pore filling type.
- Examples of water repellent materials such as soda and potash soaps are chemically active, whereas calcium soaps, resin, vegetable oil, fats, waxes and coal tar residue are the examples of chemically inactive materials.

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Bleeding Agents.

- To stop bleeding, *paraffin wax* at about 0.2–0.75 percent by mass of cement or air entrainment is used.
- Air entrainment latter is more effective but requires high degree of control.

Puzzolanas

- These are siliceous materials which are themselves inactive but react in the presence of water, with time to form compounds having cementitious properties.
- Puzzolanas react with free lime in cement and improve the durability of concrete, and reduce the rate of hardening of concret, which is the principal objection to its use.
- Examples of pozzolana are lime, fly ash, burnt clay and blast furnace slag.

Expansion Producing Admixtures

- These are used to counteract the drying shrinkage of concrete.
- Granulated iron and chemicals are most effective.

Bonding Admixtures

- These are used to join the old and new concrete surfaces or between the successive concrete lifts.
- Examples are *synthetic latex emulsions* - made from natural rubber, synthetic rubber, polyvinyl chloride.

CORROSION OF REINFORCING STEEL

- The mechanism of corrosion of reinforcing steel, embedded in concrete, is attributed to electrochemical action.
- Differences in the electrochemical potential on the steel surface results in the formation of anodic and cathodic regions, which are connected by some salt solution acting as an electrolyte.
- Steel in freshly cast concrete is generally free from corrosion because of the formaiton of a thin protective film of iron oxide due to the strongly alkaline environment produced by the hydration of cement.
- This passive protection is broken when the pH value of the regions adjoining the steel falls below about 9.
- The can occur either by carbonation (reaction of carbon dioxide in the atmosphere with the alkalis in the cement paste).
- The electrochemical process of corrosion takes place in the presence of the electrolytic solution and water and oxygen.
- Cathodic protection is the most effective (although expensive) way of arresting corrosion.

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CONVENTIONAL QUESTIONS

1. What do you mean by water-cement ratio? Explain its significance in the preparation of concrete. (1987)

2. What is meant by workability of concrete? Describe the test used to measure the workability of concrete in the field. (1988)

3. What are the strength tests prescribed for concrete? Briefly describe them. (1989)

4. Explain the following and bring out their significance : (1991)

   (i) Water-cement ratio

   (ii) Fineness modulus

   (iii) Bulking of sand

   Describe the method of determining the compacting Factor for fresh concrete. What does it indicate? (1991)

5. What are the different methods of designing a concrete mix using given aggregates and cement for a required strength? Describe any one of them. (1993)

6. What are the factors that influence the strength of cement concrete? Briefly discuss the effects of water-cement ratio and workability on the strength of concrete. (1995)

7. What do you understand by 'workability of concrete'? Describe briefly a test for its in-situ determination. What should be the values of observation from this test for concrete used for different purposes?

8. What is non -destructive testing of concrete? What are its relative merits. Name the methods of non-destructive testing and explain briefly any one method. (1998)

9. Describe the workability of fresh concrete and its measurement in the light of statement that workability is a composite property and each test measures only a particular aspect of it. (2000)

10. Using a mix design procedure, mix proportion for the desired grade of concrete have been obtained as 1 : 2.1 : 3.5 (by mass) with water-cement ratio of 0.5 and air content of 3 percent. Calculate the weights of individual ingredients required to make 0.25 m^3 concrete. The specific gravities of cement, sand and aggregate wee 3.15, 2.65 and 2.70, respectively. (2000)

11. What is meant by the term 'Workability of concrete'? List the methods used for measurement of workability of concrete. Clearly indicate the aspect of workability measured by each method. (2002)

12. Explain the following :

    (i) Grading zones of sand

    (ii) Grading of coarse aggregate (2002)

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13. Calculate the quantities of cement, sand and coarse aggregate required to produce one cubic meter of concrete for mix properties of 1 : 40 : 2.80 (by volume) with water-cement ratio of 0.48 (by mass). Bulk densities of cement, sand and coarse aggregates are 14.7, 16.66 and 18.68 kN/m3, respectively. Percentage of entrained air is 2.0. Specific gravities of cement, sand and coarse aggregate are 3.15, 2.6 and 2.5, respectively. **(2003)**

14. Describe in brief the rebound hammer method of non destructive testing of concrete. **(2004)**

15. Define 'workability of concrete'. What are the factors affecting workability of concrete? **(2004)**

16. Estimate the quantities of cement, fine aggregate and coarse aggregate per cubic meter of concrete if the void ratio in cement is 62%, fine aggregate is 41% and coarse aggregate is 45%. The material properties are as follows :

    Mix : 1 : 2 : 4 with a w/c of 0.55, one bag of cement contains 50 kg of cement and its density is 1440 kg/m^3. The density of fine aggregate is 1700 kg/m^3 and coarse aggregate is 1600 kg/m^3 respectively. One bag of cement is equal to 34.7 liters. **(2006)**

17. Give a brief description of slump test for measurement of workability of concrete and its merits and demerits. What are the slump values recommended for different types of works? **(2008)**

18. Draw a sketch showing the typical creep strain time curve under uniaxialcompression for concrete. **(2009)**

19. Briefly describe the admixtures generally used in concrete and the properties they impart to the concrete. **(2009)**

20. Give a detailed account of the cylinder splitting test of concrete.

21. What are the limitations of the above test in evaluating the real tensile strength of concrete. **(2009)**

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OBJECTIVE QUESTIONS

1. The split tensile strength of M 15 grade concrete when expressed as percentage of its compressive strength is

   (a) 10 to 15% (b) 15 to 20%
   (c) 20 to 25% (d) 25 to 30%

2. The approximate ratio between the strengths of cement concrete at 7 days and at 28 days is

   (a) 3/4 (b) 2/3
   (c) 1/2 (d) 1/3

3. Modulus of elasticity of M 25 concrete as determined by formula of IS:456 is

   (a) 1,24,500 MPa (b) 90,125 MPa
   (c) 28,500 MPa (d) 16,667 MPa

4. Tensile strength of concrete is measured by

   (a) direct tension test in the universal testing machine
   (b) applying compressive load along the diameter of the cylinder
   (c) applying third point loading on a prism
   (d) applying tensile load along the diameter of the cylinder

5. The approximate ratio of strength of 15 cm × 30 cm concrete cylinder to that of 15 cm cube of the same concrete is

   (a) 1.25 (b) 1.00
   (c) 0.85 (d) 0.50

6. General shrinkage in cement concrete is caused by

   (a) carbonation
   (b) stressed due to external load
   (c) drying with starting with a stiff consistency
   (d) drying with starting with a wetter consistency

7. While concreting in cold weather where frosting is also likely, one uses

   (a) high quality Portland cement with minimum additives
   (b) high alumina cement with calcium chloride additives
   (c) Portland cement together with calcium chloride additives
   (d) a mixture of high alumina cement and Portland cement

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8. Weight-batching proceeds on

(a) the assumption of the declared weight in each bag of cement

(b) weighing the contents of each bag

(c) accurately estimating the weight of each material to be used in ecah batch

(d) the assumption of correct dry weight of each size range of each material and the weight of water.

9. The modulus of elasticity (E) of concrete is given by

(a) $E = 1000\ f_{ck}$ (b) $E=5700\sqrt{f_{ck}}$

(c) $E=5500\sqrt{f_{ck}}$ (d) $E=10,000\sqrt{f_{ck}}$

10. The optimum number of revolutions over which concrete is required to be mixed in a mixer machine is

(a) 10 (b) 20

(c) 50 (d) 100

11. Consider the following statements:
Higher water-cement ratio in concrete result in

1. stronger mix
2. better workable mix
3. a weak mix
4. less bleeding

Which of these statements are correct?

(a) 1 and 2 (b) 2 and 3

(c) 3 and 4 (d) 1 and 4

12. A splitting tensile test is performed on cylinder of diameter D and length L. If the ultimate load is P, then splitting tensile strength of concrete is given by

(a) $\frac{P}{\pi DL}$ (b) $\frac{2P}{\pi DL}$

(c) $\frac{4PL}{\pi D^3}$ (d) $\frac{4PD}{\pi L^3}$

13. Match **List-I** (Admixtures) with **List-II** (Chemicals) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Water-reducing admixture	1. Sulphonated melanin formaldehyde
B. Air-entraining agent	2. Calcium chloride
C. Superplasticiser	3. Lignosulphonate
D. Accelerator	4. Neutralised vinsol resin

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Codes :

	A	B	C	D
A.	2	4	1	3
B	1	3	4	2
C.	3	4	1	2
D.	3	4	2	1

14. The capacity of a "28S type" concrete mixer is $0.8m^3$. For mixing one cubic meter of concrete, the quantity of cement required is 5.5 bags. In order to avoid fractional usage of cement bags, the volume of concrete (in m^3) to be mixed bper batch will be

(a) 0.79 (b) 0.55

(c) 0.73 (d) 0.44

15. Batching refers to

(a) controlling the total quantity at each batch

(b) weighing accurately, the quantity of each material for a job before mixing

(c) controlling the quantity of each material into each batch

(d) adjusting the water to be added in each batch according to the moisture content of the materials being mixed in the batch.

16. Consider the following strengths of concrete:

1. Cube strength
2. Cylinder strength
3. Split-tensile strength
4. Modulus of rupture

The correct sequence in increasing order of these strengths is

(a) 3, 4, 2, 1 (b) 3, 4, 1, 2

(c) 4, 3, 2, 1 (d) 4, 3, 1, 2

17. Consider the following statements :

The effect of an air entrainment in concrete is to

1. increase resistance to freezing and thawing
2. improve workability
3. decrease strength

Which of these statements is/are correct?

(a) 2 and 3 (b) 1 and 3

(c) 1 alone (d) 1,2 and 3

18. As per IS Code of Practice, concrete should be cured at

(a) 5°C (b) 10°C

(c) 27°C (d) 40°C

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19. The correct sequence of workability test(s)/ methods(s) in the order of their application from low to high workability is

(a) slump test, compacting factor test and vee-bee consistometer
(b) compacting factor test, vee-bee consistometer and slump test.
(c) vee-bee consistometer, slump test and compacting factor test.
(d) vee-bee consistometer, compacting factor test and slump test.

20. While testing the compressive strength of cement concrete, the correct standard conditions (vis., temperature, age, humidity and size of the specimen) to be maintained as per I.S. are

(a) 27 + 3°C, 28 days, 90% and 15 cm^3
(b) 26 + 2°C, 21 days, 80% and 15 cm^3
(c) 25 + 1°C, 14 days, 75% and 15 cm^3
(d) 27 + 3°C, 7 days, 70% and 10 cm^3

21. Which one of the following types of concrete is most suitable in extreme cold climates?

(a) Air-entrained concrete
(b) Ready mix concrete
(c) Vacuum concrete
(d) Coarse concrete

22. Match **List-I** (Workability test) with **List-II** (Measurements) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Slump test	1. 300-500 mm
B. Compacting factor	2. 75-125 mm
C. Vee-bee test	3. 0.80 to 0.98
D. Flow test	4. 0 to 10 sec

Codes:

	A	B	C	D
(a)	2	4	3	1
(b)	1	3	4	2
(c)	1	4	3	2
(d)	2	3	4	1

23. Consider the following statements :

Curing of concrete by steam under pressure

1. increases the compressive strength of concrete
2. reduces the shear strength of concrete
3. increases the speed of chemical reaction.

Which of these statement is/are correct?

(a) 1,2 and 3
(b) 1 alone
(c) 2 and 3
(d) 3 alone

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24. Consider the following statements:

Ultrasonic pulse velocity test to measure the strength of concrete is

1. used to measure the strength of wet concrete
2. used to obtain estimate of concrete strength of finished concrete elements
3. a non-destructive test

Which of these statements are correct?

(a) 1, 2 and 3 (b) 2 and 3
(c) 1 and 2 (d) 1 and 3

25. The length of time for which a concrete mixture will remain plastic is usually more dependent on

(a) the setting time of cement than on the amount of mixing water and atmospheric temperature
(b) the atmospheric temperature than on the amount of mixing water and the setting time of cement
(c) the setting time of cement and the amount of mixing water than on atmospheric temperature than on the setting time of cement
(d) the amount of mixing water used and atmospheric temperature than on the setting time of cement

26. Match List-I (Admixture) with List-II (Action in concrete) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Calcium lignosulphonate	1. Anti-bleeder
B. Aluminium powders	2. Retarder
C. Tartaric Acid	3. Air entrainer
D. Aluminium sulphate	4. Water reducer

Codes:

	A	B	C	D
(a)	3	2	1	4
(b)	4	3	2	1
(c)	3	4	1	2
(d)	4	2	3	1

27. Bleeding of concrete leads to which of the following?

1. Drying up of concrete surface
2. Formation of pores inside
3. Segregation of aggregate
4. Decrease in strength

Select the correct answer using the codes given below:

(a) 1 only (b) 1 and 2
(c) 1 and 3 (d) 2 and 4

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28. Match List-I (Material characteristics) with List-II (Property of concrete) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Water cement ratio	1. Durability
B. Water content	2. Compressive strength
C. Minimum cement content	3. Stability of mix
D. Segregation	4. Workability

Codes :

	A	B	C	D
(a)	4	1	3	2
(b)	2	4	3	1
(c)	4	1	2	3
(d)	2	4	1	3

29. Stress-strain curve of concrete is
(a) a perfect straight line up to failure
(b) straight line up to 0.002% strain value and then parabolic up to failure
(c) parabolic up to 0.002% strain value and then a straight line up to failure
(d) hyperbolic up to 0.002% strain value and then a straight line up to failure

30. Match List-I (Material used in individual batching of concrete) with List-II (Tolerance when batch weight exceeds 30% of scale capacity) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Cement	1. ± 0.3% of scale capacity
B. Water	2. ± 1% of scale capacity
C. Aggregates	3. ± 2% of scale capacity
D. Admixtures	4. ± 3% of scale capacity

Codes :

	A	B	C	D
(a)	1	2	3	4
(b)	1	2	4	3
(c)	3	4	1	2
(d)	4	3	2	1

31. Consider the following statements:
1. The crushing strength of concrete is fully governed by water-cement ratio.
2. Vibration has no effect on strength concrete at high water-cement ratios.
3. Workability of concrete is affected by improper grading of aggregates.

Which of these statement is/are correct?
(a) 1, 2 and 3 (b) 2 and 3 only
(c) 2 only (d) 3 only

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32. For different concrete specimens, each hydrated to the same degree, the permeability is
(a) Higher with lower water cement ratio and higher cement content.
(b) Lower with lower water cement ratio and higher cement content.
(c) Lower with higher water cement ratio and lower cement content.
(d) Lower with higher water cement ratio and higher cement content.

33. The use of super-plasticizers as admixture
(a) increases compressive strength of concrete
(b) permits lower water cement ratio, thereby strength is increased
(c) reduces the setting time of concrete
(d) permits lower cement content, thereby strength is increased

34. Consider the following statements:
For increasing the workability of concrete, it is necessary to
1. increase the quantity of cement
2. decrease the quantity of sand
3. alter the proportion of fine and coarse aggregates
4. decrease the quantity of water
5. use angular aggregate
Which of these statements are correct?
(a) 1,2,3,4 and 5 (b) 2,4 and 5
(c) 2 and 3 (d) 1 and 5

35. Slump and compaction factors are two diferent measures of workability of concrete. For a slump of 0 to 20 mm, what is the equivalent range of compaction factor?
(a) 0.50 – 0.70 (b) 0.70 – 0.80
(c) 0.80 – 0.85 (d) 0.85 – 0.92

36. The values of slump commonly adopted for the various concrete mixes are given below:
1. Concrete for road works : 20 to 28 mm
2. Ordinary RCC work : 50 to 100 mm
3. Columns retaining walls : 12 to 25 mm
4. Mass concrete : 75 to 175 mm
Which of the pairs given above are correctly matched?
(a) 1, 3 and 4 (b) 1 and 2
(c) 3 and 4 (d) 2 and 4

37. Consider the following pairs:

1. Hand compaction of heavily reinforced sections	:	Low workability (0-25 mm slump)
2. Concreting of shallow sections with vibrations	:	High workability (125-150 mm slump)
3. Concreting of lightly reinforced sections like pavements	:	Low workability (5-50 mm slump)
4. Concreting of lightly reinforced section by hand or heavily reinforced sections with vibration	:	Medium workability (25-75 mm slump)

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Which of the paris given above are correctly matched?

(a) 1 and 2 (b) 2 and 3

(c) 3 and 4 (d) 1 and 3

38. Consider the following statements regarding the phenomenon of bulking of sand:

1. It is due to film of water around sand particles.
2. It is due to capillary action.
3. It is more in finer sands.

Which of these statements is/are correct?

(a) 1,2 and 3 (b) 1 and 3

(c) 2 and 3 (d) 1 and 2

39. On which one of the following factors, does strength of concrete depend primarily?

(a) Quality of coarse aggregate (b) Quality of fine aggregate

(c) Fineness of cement (d) Water-cement ratio

40. Consider the following statements:

Cement concrete is a/an

1. elastic material
2. visco-elastic material
3. visco-plastic material

Which of these statement is/are correct?

(a) 1,2 and 3 (b) 2 and 3

(c) 2 only (d) 1 only

41. Why is super plasticizer added to concrete?

1. To reduce the quantity of mixing water.
2. To increase the consistency
3. To reduce the quantity of cement.
4. To increase resistance to freezing and thawing

Select the correct answer using the codes given below:

(a) 1,2 and 4 (b) 1,3 and 4

(c) 2 and 4 (d) 4 only

42. _____ principle of concrete hammer for non-destructive test based?

(a) Rebound deflections (b) Radioactive waves

(c) Ultrasonic pulse (d) Creep-recovery

43. What is the correct sequence of operations involved in concrete production?

(a) Batch—mixing—handling—transportation

(b) Mixing — batching — handling —transportation

(c) Transportation — handling — mixing — batching

(d) Handling— transportation— mixing — batching

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44. What is the approximate ratio of the strength of cement concrete at 7 days to that at 28 days curing?
(a) 0.40 (b) 0.65
(c) 0.90 (d) 1.15

45. Which one of the following properties of cement concrete is ascertained by conducting compaction factor test?
(a) Bulk density (b) Compressive strength
(c) Modulus of rupture (d) Workability

46. The mix design for pavement concrete is based on the
(a) flexural strength (b) characteristic compressive strength
(c) shear strength (d) bond strength

47. In what context is the slump test performed?
(a) Strength of concrete (b) Workability of concrete
(c) Water-cement ratio (d) Durability of concrete

48. Consider the following statements:
Curing of concrete is necessary because
1. concrete needs more water for chemical reaction
2. it is necessary to protect the water initially mixed in concrete from being lost during evaporation
3. penetration of surrounding water increases the strength of concrete?
Which of these statement is/are correct?
(a) 1,2 and 3 (b) 1 and 3 only
(c) 2 only (d) 3 only

49. Which one of the following is employed to determine strength of hardened existing concrete structure?
(a) Bullet test (b) Kelly ball test
(c) Rebound hammer test (d) Cone penetrometer

50. Which one of the following is the correct expression for the target mean strength f_t of concrete mix?
(a) $f_t = kf_{ck} + \sigma$ (b) $f_t = f_{ck} + k\sigma$
(c) $f_t = f_{ck} + \sigma$ (d) $f_t = kf_{ck} + k$
where f_{ck} is characteristic strength, k is probability factor and s is standard deviation.

51. Which factors influence the workability of concrete without sacrificing strength?
1. Fine aggregate
2. Quantity of mixing water
3. Maximum size of coarse aggregate
4. Shape of coarse aggregate

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Select the correct answer using the codes given below:

(a) 1 only (b) 2 only

(c) 1 and 2 (d) 3 and 4

52. Consider the following statements regarding cement concrete :

1. Bleeding indicates deficiency of coarser materials in the mix.
2. Segregation generally indicates poor aggregate grading

Which of these statements is/are correct?

(a) 1 only (b) 2 only

(c) Both 1 and 2 (d) Neither 1 nor 2

53. Match the sequence of determination of components of a concrete mix as per Indian Standard method of mix design and select the correct answer using the codes given below the lists :

List-I	List-II
A. Cement content	1. First step
B. Aggregate content	2. Second step
C. Water content	3. Third step
D. Water-cement ratio	4. Fourth step

Codes :

	A	B	C	D
(a)	1	2	4	3
(b)	3	2	4	1
(c)	3	4	2	1
(d)	1	4	2	3

54. Which factors comprise maturity of concrete?

(a) Compressive strength and flexural strength of concrete

(b) Cement content per cubic metre and compressive strength of concrete

(c) Curing age and curing temperature of concrete

(d) Age and aggregate content per cubic metre of concrete

55. Which of the following tests compares the dynamic modulus of elasticity of samples of concrete?

(a) Compression test (b) Ultrasonic pulse velocity test

(c) Split test (d) Tension test

56. Which one of the following is correct regarding the most effective requirements of durability in concrete?

(a) Providing reinforcement near the exposed concrete surface

(b) Applying a protective coating to the exposed concrete surface

(c) Restricting the minimum cement content and the maximum water cement ratio and the type of cement

(d) Compacting the concrete to a greater degree

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57. Consider the following statements about the air entraining admixture in concrete:
   1. Improve workability
   2. Improve durability
   3. Reduce segregation during placing
   4. Decrease concrete density

   Which of these statements are correct?

   (a) 1,2, 3 and 4 (b) 1 and 2 only
   (c) 2 and 3 only (d) 3 and 4 only

58. Consider the following statements:

   Admixtures are added to concrete to
   1. increase its strength
   2. reduce heat of hydration
   3. delay the setting of cement
   4. reduce water-cement ratio

   Which of these statements is/are correct?

   (a) 1 only (b) 1 and 2
   (c) 2 and 3 (d) 3 and 4

59. Consider the following statements:
   1. Strength of concrete cube is inversely proportional to water-cement ratio.
   2. A rich concrete mix gives a higher strength than a lean concrete mix since it has more cement content.
   3. Shrinkage cracks on concrete surface are due to excess water in mix.

   Which of these statements is/are correct?

   (a) 1,2 and 3 (b) 1 and 2 only
   (c) 2 only (d) 2 and 3 only

The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below :

Codes :

(a) Both A and R are true and R is correct explanation of A

(b) Both A and R are true but R is not a correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

60. **Assertion (A):** The splitting test for determining the tensile strength of concrete gives more uniform results than any other tension test.

   Reason (R) : The splitting test moulds can be used for casting specimens for both compression and tension tests.

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61. **Assertion (A) :** One year strength of continuously moist cured concrete is 40% higher than that of 28 day strength, while no-moisture- curing can lower the strength to about 40%.

Reason (R) : Moist curing for the first seven to fourteen days results in a compressive strength of 70 to 80% of that of 28 day moisture curing.

62. **Assertion (A) :** For identical mix, the cube compressive strength of concrete obtained from 15 cm cube is higher than 15 cm × 30 cm cylinder compressive strength.

Reason (R) : Cube compressive strength is higher than the cylinder compressive strength because of its higher contact area under the load.

63. **Assertion (A) :** Workability of concrete is improved by air entraining agent.

Reason (R) : Air entraining agent increases concrete strength.

64. **Assertion (A) :** The use of fly ash as an admixture in concrete reduces segregation and bleeding.

Reason (R) : The use of fly ash as a replacement of sand in a lean-mix increases the workability and has no significant effect on drying shrinkage of concrete.

65. **Assertion(A) :** Calcium chloride addition in concrete proves more effective in slow-hardening portland cement than in rapid hardening cement.

Reason (R) : Calcium chloride acts as an effective accelerator thereby increasing rate of reaction.

66. **Assertion(A) :** Rebound hammer (schmat hammer) test gives only approximate estimation of strength of the concrete specimen.

Reason (R): The test represents the hardness of the surface and provides no idea of the concrete inside.

67. **Assertion (A):** Even though vibration is the best technique of obtaining a durable and strong concrete, it cannot prouduce a compact concrete, if the mix is not properly graded or designed.

Reason (R): Over-vibrating of concrete with a slump of more than 10 cm may lead to honeycombing and a top surface which is not durable.

68. **Assertion (A):** Strength of concrete is reduced due to segregation.

Reason (R): Reducing the workability of concrete mix results in segregation.

69. **Assertion (A):** The lower the difference between the minimum strength and the mean strength of a concrete mix, the lower the cement content to be used.

Reason (R): The method for controlling the difference between the minimum strength and the mean strength is quality control.

70. **Assertion (A):** Higher strength is achieved when superplasticizer is added to cement concrete mix.

Reason (R) : By adding super plasticizer, the quantity of mixing water is reduced.

71. **Assertion (A):** Inorder to obtain higher degree of workability in cement concrete, both water content and proportion of cement should be increased

Reason (R) : Increase in water cement ratio decreases the strength of cement concrete; a mix with higher workability must have higher proportion of cement in it.

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ANSWERS

1.	(b)	19.	(d)	37.	(c)	55.	(b)
2.	(b)	20.	(a)	38.	(b)	56.	(b)
3.	(c)	21.	(a)	39.	(d)	57.	(a)
4.	(b)	22.	(d)	40.	(c)	58.	(d)
5.	(c)	23.	(a)	41.	(a)	59.	(a)
6.	(d)	24.	(b)	42.	(a)	60.	(b)
7.	(b)	25.	(d)	43.	(a)	61.	(b)
8.	(d)	26.	(b)	44.	(b)	62.	(c)
9.	(b)	27.	(d)	45.	(d)	63.	(c)
10.	(b)	28.	(d)	46.	(b)	64.	(b)
11.	(b)	29.	(c)	47.	(b)	65.	(a)
12.	(b)	30.	(a)	48.	(c)	66.	(c)
13.	(c)	31.	(d)	49.	(c)	68.	(c)
14.	(c)	32.	(b)	50.	(b)	69.	(d)
15.	(b)	33.	(b)	51.	(d)	70.	(a)
16.	(a)	34.	(c)	52.	(b)	71.	(a)
17.	(d)	35.	(b)	53.	(c)		
18.	(c)	36.	(b)	54.	(c)		

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CHAPTER

3

Timber

INTRODUCTION

- Timber denotes wood which is suitable for building or carpentry or various other engineering purposes and it is applied to the trees measuring not less than 600 mm in circumference of the trunk.
- Following three terms are to be noted in connection with the timber:

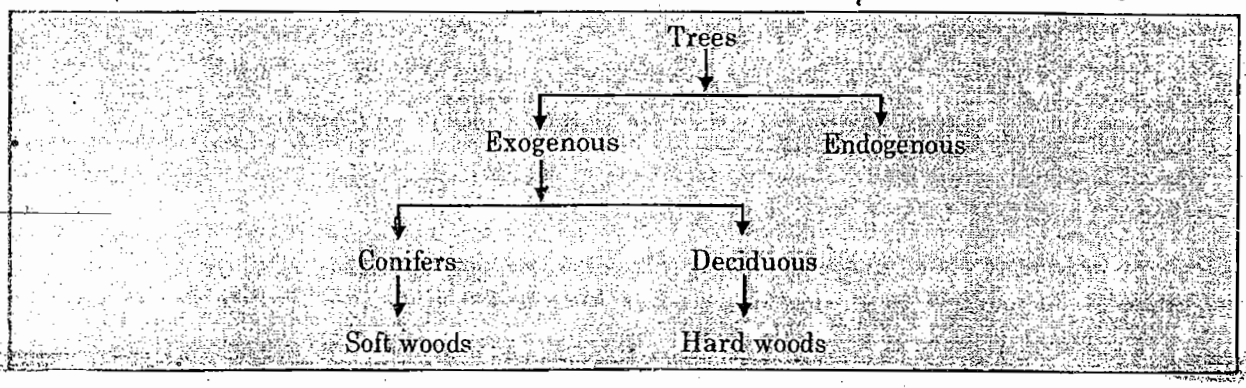
  Converted timber : Timber which is sawn and cut into suitable commercial sizes.

  Rough timber: Timber which is obtained after felling a tree.

  Standing timber: Timber contained in a living tree.
- Timber or wood, as building material, possesses a number of valuable properties such as low heat conductivity, amenability to mechanical work, small bulk density, relatively high strength, etc.
- Owing to the above mentioned advantages, wood is very widely used in buildings as doors windows, frames, temporary partition walls, etc. and in roof trusses and ceilings apart from formwork.
- But it also has some drawbacks such as susceptibility to decay and inflammability, fluctuations in properties due to changes in moisture content, variations in strength in length and across fibers, etc.
- These drawback of timber can greatly be reduced by the application of some of the modern wood processing techniques.

CLASSIFICATION OF TREE

- For the engineering purposes, the trees are classified according to their mode of growth.



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Endogenous Tree

- These trees grow inwards.
- Timber from these trees has very limited engineering applications.
- Examples of endogenous trees are bamboo, cane, palm etc.

Exogenous Tree

- These trees grow outwards
- These trees are used for making structural elements
- They are further divided as conifers and deciduous.

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

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

Differences between soft-wood and Hard-wood

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

Note :

Sometimes tree are also classified on the basis of modulus of elasticity and durability.

Durability

Group A: *Modulus of elasticity in bending above 12.5kN/mm²*

Group B: *Modulus of elasticity in bending above 9.8 kN/mm² and below 12.5 kN/mm²*

Group C: *Modulus of elasticity in bonding above 5.6 kN/mm² and below 9.8 kN/mm²*

Durability

High durability average life of 120 months and over.

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

Low durability average life of less than 60 months.

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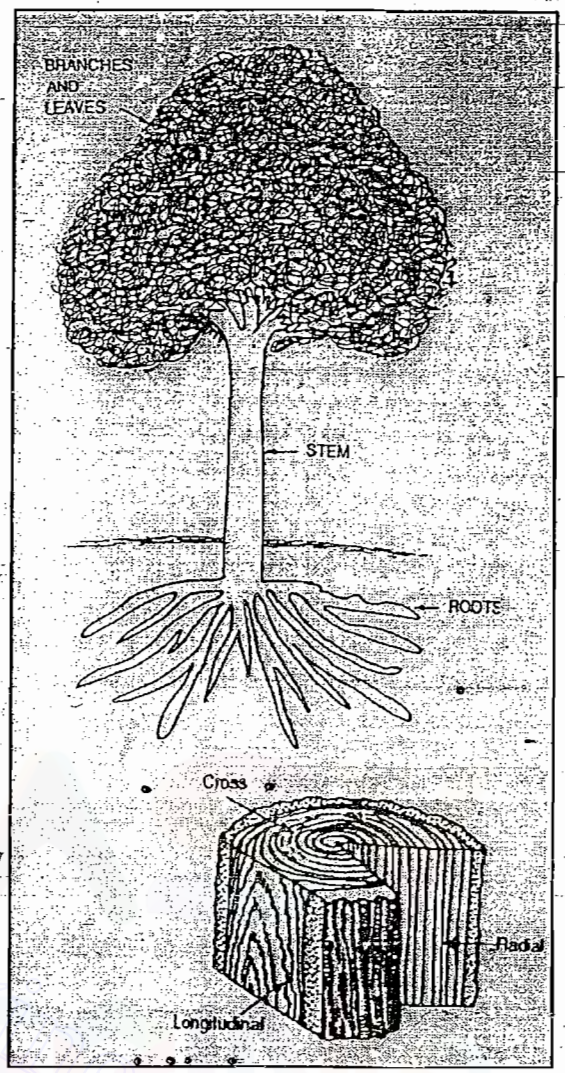
STRUCTURE OF TIMBER



- A tree basically consists of three parts:

1. Stem

If supports crown and supply water and nutrients from the roots to the leaves through branches and from leaves back to the roots.

2. Roots

If implants tree in the soil, to absorb water and mineral substances and supply it to stem.

3. Crown

If consists of leaves and branches.

- From visibility aspect, structure of tree can be divided into two categories.

  (a) Macrostructure (b) Microstructure

Macrostructure

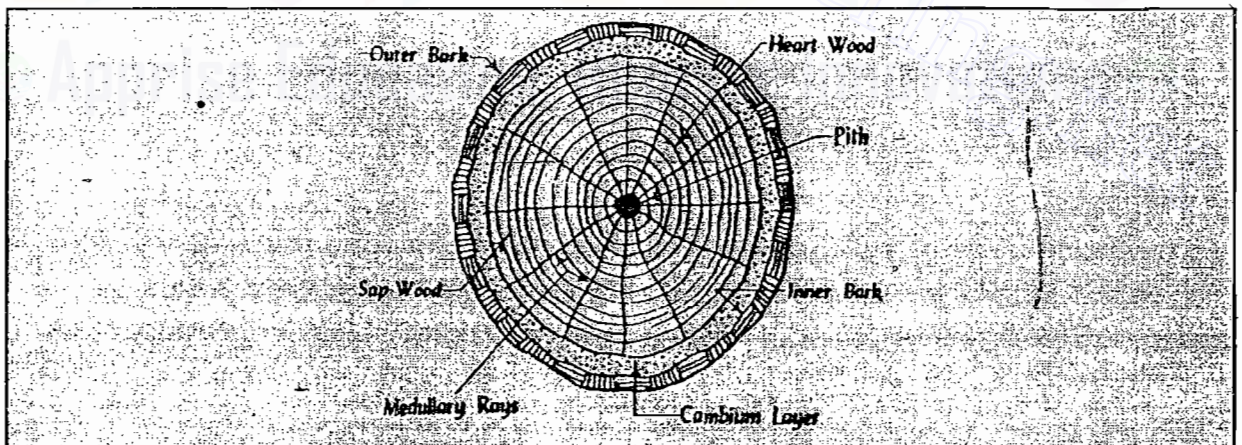
- The structure of timber visible to naked eye or at a small magnification is called macro structure.
- Macro structure of the timber can be studied by cutting the trunk in three directions.

  (a) Cross sectional

  (b) Longitudinal

  (c) Radial

- Detailed cross sectional view of the trunk of an exogenous tree is shown below



Cross-section of an exogenous tree

Following are its different components:

(a) *Pith*

- Innermost central portion or core of the tree is called the Pith or Medulla.
- It varies in size and shape for different types of trees.

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- It consists entirely of cellular tissues and it nourishes the plant in its young age.
- As the plant becomes old, the pithy dies up and decays and the sap is then transmitted by the woody fibres deposited round the pith.

(b) *Heart Wood*

- Inner annual rings surrounding the pith consistute the heart wood.
- It is usually dark in colour. As a mater of fact.
- It indicates dead portion of tree and as such, it does not take active part in the growth of tree.
- It imparts rigidity to the tree and hence it provides strong and durable timber for various engineering purposes.

(c) *Sap Wood*

- Outer annual rings between heart wood and cambium layer is known as the sap wood.
- It is usually light in colour and weight.
- It shows recent growth and it contains sap.
- The annual rings of sap wood are less sharply defined than those of heart wood. It takes active part in the growth of tree and the sap moves in an upward direction through it.
- Sap wood is also known as the Alburnum.

(d) *Cambium Layer*

- Thin layer of sap between sap wood and inner bark is known as the Cambium layer.
- It indicates sap which has yet not been converted into sap wood.
- If bark is removed due to any reason, the cambium layer gets exposed and the cells cease to be active resulting in the death of tree.

(e) *Inner Bark*

- Inner skin or layer covering the cambium layer is known as the inner bark.
- It gives protection to the cambium layer from any injury.

(f) *Outer Bark*

- Outer skin or cover of the tree is known as the outer bark. It is the outermost protective layer and it sometimes contains cracks and fissures.
- It consists of cells of wood fibre and is also known as the Cortex.

(g) *Medullary Ray*

- Thin radial fibres extending from pith to cambium layer are known as the medullary rays.
- Function of these rays is to hold together the annual rings of heart wood and sap wood.
- Rays are sometimes broken and in some varieties of trees, they are not very prominent.

Note:

Annual Rings/Growth Rings

- *These are concentric layers of wood known as growth rings or annual rings.*
- *During growth season, the wood added during the early part is different from the wood added during the late part. The early wood is softer, coarser and more porous than the late wood. Growth rings are apparent because of this difference between the early wood and the late wood.*

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- *In some trees such differences may not exist. In such cases the growth rings may not be distinct and may not be annual.*
- *The growth rings are particularly distinct in the case of coniferous woods.*

Microstructure

- The structure of wood apparent only at great magnification is called the microstructure.
- When studied under a microscope, it is clear that wood consists of living and dead cells of various sizes and shapes.

PROPERTIES OF TIMBER

Density and Specific Weight

- The true specific gravity of wood is approximately equal for all species and averages1.54 whereas the specific weight and apparent specific gravity vary with density of wood.
- Percentage of moisture in the wood has a very large effect upon the specific weight and hence true comparisons of this property can only by made on dry specimens.
- Is code tells that weight of timber should be noted at 12% moisture content.

Moisture Content

- Timber by nature is hygroscopic i.e. it absorbs water from surrounding air.
- Even when it is sufficiently dried there is no gaurantee that timber will not absorb moisture from air resulting in swelling and shrinkage.
- Therefore moisture content at any given moment in a piece of timber depends upon the atmospheric contidions to which the timber is exposed, the stage reached in the drying process, dimensions of the piece and the species.
- Recommended moisture content for structural elements is 12–20 percent for doors, and 10–16 percent for windows.
- Hence drying of timber causes shrinkage while absorption of water by timber causes swelling.
- Timber is not a homogeneous material (i.e. Anisotropic) and hence the shrinkage along different directions is not uniform.
- Green timber shrinks least along its length, much more along the radial direction and maximum along the circumference.
- If should be noted that drying of timber below fiber saturation point results in shrinkage.
- Fiber saturation point is % moisture content at which cell walls are saturated cell cauity contains no water.
- Sudden and first drying of timber causes remoal of water from cell wall and results in shrinkage causing cracking.
- If a dry piece is kept in saturated atmosphere it can absorb about 15% moisture of its weight, this water goes into cell walls which tend to swelling of timber.
- The figures vary considerably for different species of timber but on an average, the shrinkage is about 0.1% along the length, 3 to 5% along the radius and 10 to 15% along the circumference.

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Note:

Permissible Moisture content:

IS:287–1973 lays down the maximum permissible moisture content for different zones and for different uses and country has been divided into 4 zones as per average relative humidity as:

Zone I — less than 40%

Zone II — 40 to 50%

Zone III — 50 to 67%

Zone IV — 67% and above

Uses	*Moisture content % maximum in zone*			
	I	II	III	IV
Aircraft	12	12	14	15
Agricultural implements	12	14	16	16
Beams and refters	12	14	17	20
Crats and Vehicles	10	12	14	16
Doors and Windows:				
50 mm and above	10	12	14	16
less than 50 mm	8	10	12	14
Furniture and cabinet making	10	12	14	15
Pattern making	8	10	12	14
Flooring strip for general purpose	8	10	10	12

Heat Conductivity

- Heat conductivity of timber is quite low.
- Heat conductivity along the fibers is 1.8 times greater than across the fibers.

Sound Conductivity

- Timber has high conductivity.
- Velocity of sound in timber is 2 – 17 times greater than that of air.

Compressive Strength

- Compressive strength is determined from test and two types of strengths are identified, along the grain and across the grain.
- When timber is subjected to compressive force acting parallel to grain (i.e. parallel to the axix of growth in logitudinal direction), wood is found to be one of the strongest structural material.
- Strength parallel to the grain is important for column, props, posts, etc. to avoid buckling and failure in bending before crushing.
- Strength of timber across the grain (i.e. perpendicular to the grain) is important in case of beams, sleepers, rollers wedges bearing blocks etc.

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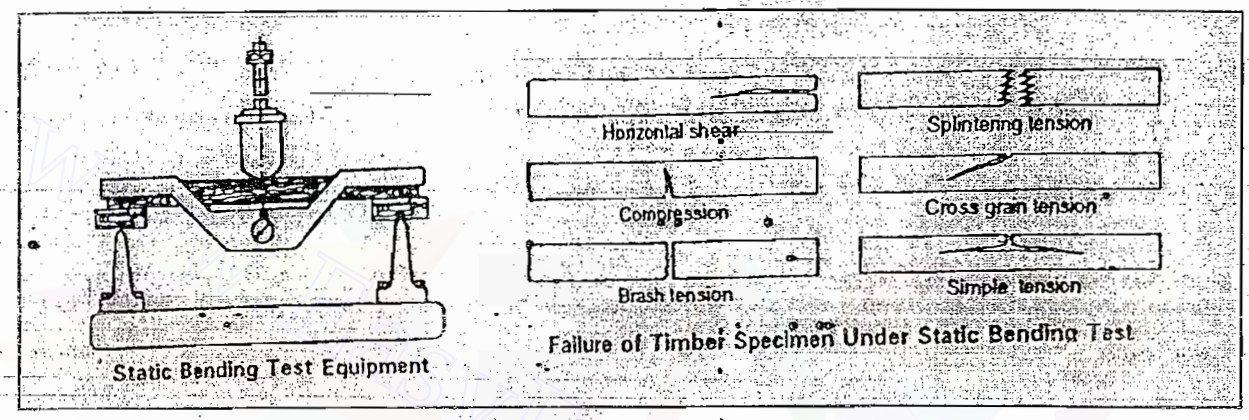
Tensile Strength

- Timber is stronger in tension along the grain of the order of 80–190N/mm².
- Across the grain tensile strength of timber is low.
- Tensile strength along the grain is 2–4 times stronger than compressive strength.
- Timber as a tension member is rarely used because difficulty is encountered is designing end connections such that tensile strength of piece can be developed.

Bending Strength

- Timber stands well during static bending due to which it is widely used for beams, slabs, trusses etc.
- Static bending strength is measured by one point loading test.

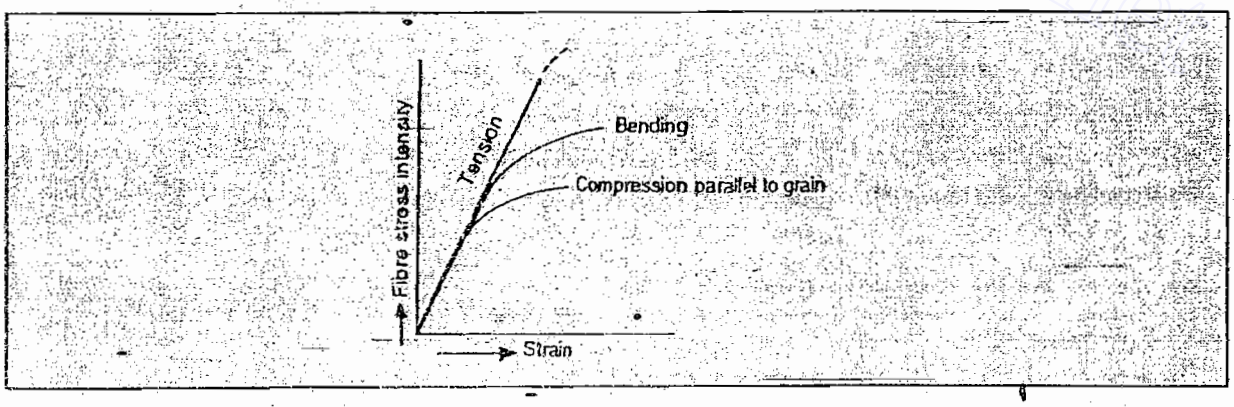


Shear Strength

- Wood has low shearing strength of 65–14.5 N/mm² along the fibres.
- Resistance of wood to cutting across the fibres is 3 to 4 times greater than that along the fibres, but pure shear generally does not take place since the fibres are also subjected to crushing and bending.

Note:

Relative stress strain curve for a timber under tension compression and in bending, prallel to grain is a below:



- Modulus of Elasticity of timber is generally 0.5 – 1.0 × 10⁴N/mm². and its ratio is longitudinal to transverse direction is 1– 2 times.

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CLEAVABILITY

- It refers to the splitting strength of timber.
- The property has to be referred to directions such as radial and tangential splitting.
- High resistance to cleavage is improtant for nailing and screwing while low splitting strength is important for use as firewood.

CHARACTERISTICS OF GOOD TIMBER

Following are the characteristics or qualities of a good timber:

(a) *Appearance*
A freshly cut surface of timber should have hard and shining appearance.

(b) *Colour*
The colour of timber should be dark light colour usually indicates timber with low strength.

(c) *Smell*
A good timber should have sweet smell. An unpleasant smell indicates decayed timber.

(d) *Defects*
A good timber should be free from serious defects such as knots, flaws, shakes, etc.

(e) *Sound*
A good timber should give out a clear ringing sound when struck. A dull heavy sound, when struck indicates decayed timber.

(f) *Structure*
It should be uniform. The fibres should be firmly added. The medullary rays should be hard and compact. The annual rings should be regular and they should be closely located.

(g) *Strength*
A good timber should be strong for working as structural member such as joist, beam, rafter, etc. It should be capable of taking loads slowly or suddenly. It should also possess enough strength in direct and transverse directions.

(h) *Hardness*
A good timber should be hard i.e. it should offer resistance when it is being penetrated by another body.

(i) *Durability*
A good timber should be durable. It should be capable of resisting the action of fungi insects, chemicals, physical agencies and mechanical agencies.

(j) *Elasticity*
This is the property by which timber returns to its original shape when load causing deformation is removed.

(k) *Fibres*
The timber should have straight fibres.

(l) *Fire Resistance*
A dense wood offers good resistance to the fire and it requires sufficient heat to cause a flame.

(m) *Shape*
A good timber should be capable of retaining its shape during conversion or seasoning. It should not bow or warp or split.

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(n) Toughness

A good timber should be tough i.e. it should be capable of offering resistance to the shocks due to vibrations.

(o) Water Permeability

A good timber should have low water permeability which is measured by the quantity of water filtered through a unit surface area of specimen of wood.

ADVANTAGES OF TIMBER

- In terms of specific strength, i.e. ratio of strength to unit weight, timber is superior to many other building materials.
- Timber can be used for both load bearing structures and non-load bearing elements.
- It can be easily converted to any shape and size.
- With the advant of superior adhesives and other forms of timber connectors, timber connections are easy to make.
- The wastage in timber construction is less because all wastes can be put to one use or the other.
- It has high resale and salvage value.
- Timber has better insulating properties than many other materials.
- Durability of timber can be very high, if properly seasond and preserved.
- Timber construction is light in weight and can be made economical.

DISADVANTAGES OF TIMBER

- It is likely to crack, warp and decay, if not properly seasond and not treated with the preservatives.
- It is not suitable for cyclonic weather and for places subjected to the natural calamities.
- It requires careful regular maintenance.
- It is subjected to the risk of fire.
- If not locally available, it proves to be costly.

DEFECTS IN TIMBER

- Timber being a natural product is rarely free from diseases and imperfections.
- Defects affect the quality reduce quantity of useful wood, reduce the strength, spoil the appearance and favour its decay.
- Defects in timber can be classified as follows.
  (1) Defects due to conversion
  (2) Defects due to fungi
  (3) Defects due to insects
  (4) Defects due to natural forces
  (5) Defects due to seasoning.

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Defects Due to Conversion

- During the process of converting timber to the commercial form the following defects may occur:

  (i) ***Chip Mark :*** It is indicated by the marks or signs placed by chips on the finished surface of timber. It may also be formed by the parts of a planing machine.

  (ii) ***Diagonal grain :*** It is formed due to improper sawing of timber and indicated by diagonal mark on straight grained surface of timber.

  (iii) ***Torn grain :*** It is caused when a small depression is formed on the finished surface of timber by falling of a tool.

  (iv) ***Wane :*** It is denoted by the presence of original rounded surface on the manufactured piece of timber.

Defects Due to Fungi

- The durability of timber depends to a large extent upon the conditions under which it is used. Fungi are a system of plant organisms which live on and attack timber and cause it to rot and decay.
- They attack timber only when the following two conditions are satisfied simultaneously:

  (1) Moisture content of timber is above 20 per cent.

  (2) Presence of air and warmth for the growth of fungi.
- If any of the above condition is absent, the decay of wood the to fungi would not.
- Therefore the dry wood having moisture content less than 20% will remain should for centuries.
- Also wood submerged in water will not be attacked by fungi because of absence of air.

Following defects are caused in the timber by the fungi:

(a) ***Blue stain :*** Sap of wood is stained to bluish colour by the action of certain type of fungi.

(b) ***Brown rot :*** Rot is decay or disease of timber. Therefor fungi of certain types remove cellulose compounds from wood and it attains brown colour. This is known as the brown rot.

(c) ***Dry rot :*** Fungi of certain types feed on wood and during feeding, they attack on wood and convert it into dry powder form. This is known as the dry rot.

(i) Dry rot occurs at places where there is no free circulation of air such as improperly ventilated basements, rooms, etc. and in damp situations like kitchen, toilets, etc.

(ii) Unseasoned soft woods and sap wood are easily attacked by dry rot.

(iii) If timber is not properly stored after being felled down, it is liable for the attack of dry rot.

(iv) Most favorable conditions for the rapid growth of fungus responsible for dry rot are absence of sunlight, dampness, presence of sap, stagnant air and warmth.

(v) Dry rot is also caused by charring, painting and tarring the unseasoned timber.

(vi) Dry rot can be prevented by using well-seasoned timber free from sap.

(vii) When part of timber is seriously affected by dry rot, the damaged portion may be completely removed and the remaining unaffected portion should be painted with a solution of copper sulphate.

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(d) ***Heart rot :*** It is formed when a branch has come out of a tree and heart wood is exposed to the attack of atmospheric agents. Ultimately the tree becomes week and it gives out hollow sound when struck with a hammer.

(e) ***Sap Stain:*** Fungi of certain types do not bring about the complete decay of timber. But they feed on cell contents of sap wood. Then the sap wood loses its colour. This is known as the sap stain. It generally occurs when moisture content goes beyond 25%.

(f) ***Wet rot :*** Some varieties of fungi cause chemical decomposition of wood of the timber and in doing so, they convert timber into a greyish brown powder. This is known as the wet rot.

(i) *Alternate dry and wet conditions favour the development of wet rot*

(ii) *If unseasoned or improperly seasoned timber are exposed to rain and wind, they become easily liable for the attack of wet rot.*

(iii) *To prevent wet rot, the well-seasoned timber should be used for exterior work or for underground work and it should be covered by tar or paint for protection against moisture.*

(g) ***White rot :*** This defect is just the opposite of brown rot. Certain types of fungi attack lignin of wood and the wood assumes the appearance of a white mass consisting of cellulose compounds.

Defects Due to Insects

Insects usually causing decay of timber are:

(a) ***Termites***

- These are also known as white ants
- They make tunnels inside the timber in different directions at the center leaving outer shell intact.
- Therefore timber piece attacked by termites may look sound till it completely fails.
- Few good timbers such as teak, sal, etc. can resist the attack of while ants.

(b) ***Beetles***

- They are small insects forming 2mm diameter pin holes causing decay of timber by converting them into fine powder leaving outer shell intact.
- They attack sap wood of all species of hard wood.

(c) ***Marine Borers***

- These are generally found in the saltly water most of the varieties of marine borers do not feed on wood.
- But they make holes or bore tunnels in wood for taking shelter.
- Diameter and length of these holes may go as high as 25mm and 60 mm respectively.
- Wood attacked by marine borers loses colour and strength.
- No timber is completely immune from the attack of marine borers.

Defects Due to Natural Forces

- Main natural forces responsible for causing defects in timber are abnormal growth and rupture of tissues.

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Defects caused by these forces are:

a) Burls

- It is also known as the excrescences and they are particularly formed when a tree has received shock or injury in its young age.
- Due to such injury, the growth of tree is completely upset and irregular projections appear on the body of timber.

b) Callus

- It indicates soft tissue or skin which covers the wound of a tree.

(c) Chemical stain

- Wood is sometimes discoloured by the chemical action caused with it by some external agency. This is known as the chemical stain.

(d) Coarse grain

- If a tree grows rapidly, the annual rings are widened. It is known as the coarse grained timber. Such timber possesses less strength.

(e) Dead Wood

- Timber which is obtained from dead standing trees contains dead wood. It is indicated by light weight and reddish colour.

(f) Druxiness

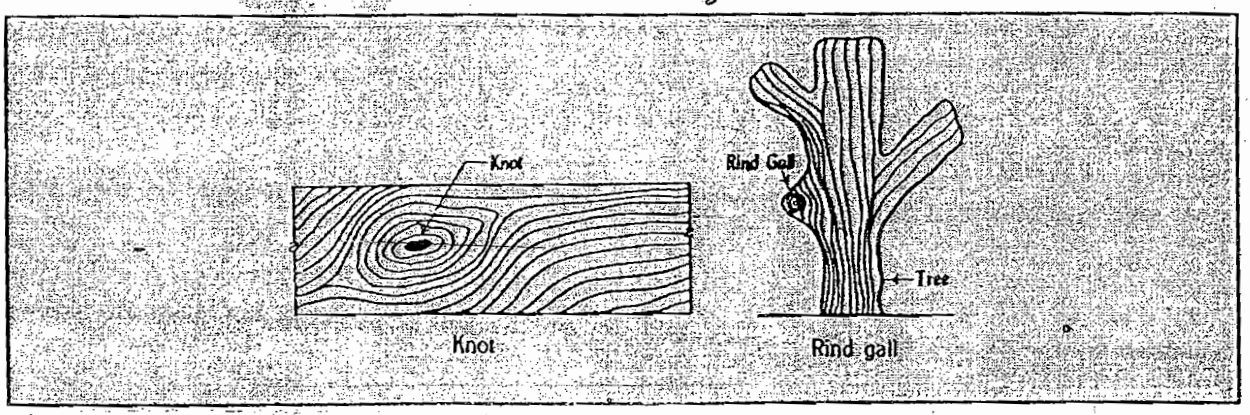
- It is indicated by white decayed spots which are concealed by healthy wood. They are probably formed for the access of fungi.

(g) Foxiness

- It is indicated by red or yellow tinge in wood or reddish brown stains or spots round the pith of tree discolouring the timber.
- It is caused either due to poor ventilation during storage or by commencement of decay die to over-maturity or due to growth of tree in a marshy soil.

(h) Knots

- These are the bases of branches or limbs which are broken or cut off from the tree.
- Portion from which the branch is removed receives nourishment from the stem for a pretty long time and it ultimately results in the formation of dark hard rings which are known as the knots.
- As continuity of wood fibres is broken by knots they form a source of weakness.



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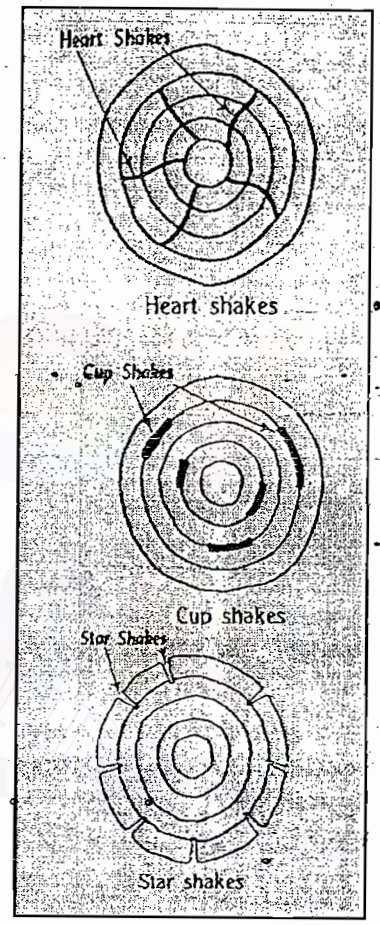
(i) Rind Galls

- Ring means bark and gall indicates abnormal growth. Hence peculiar curved swellings found on the body of a tree are known as the Rind galls.
- They develop at points from where branches are improperly cut off or removed.
- They are rarely found in a tree and the timber in this part is very weak and not durable.

(j) Shakes

- It is longitudinal separations in the wood between the annual rings.
- This lengthwise separations reduce the allowable shear strength without much effect on compressive and tensile strength.
- If both shakes and checks are present near the neutral plane of beam, then beam is more prone to fail in horizontal shear.
- Separations make the wood undesirable when appearance is important.



(i) Heart Shake :

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

(ii) Cup Shake :

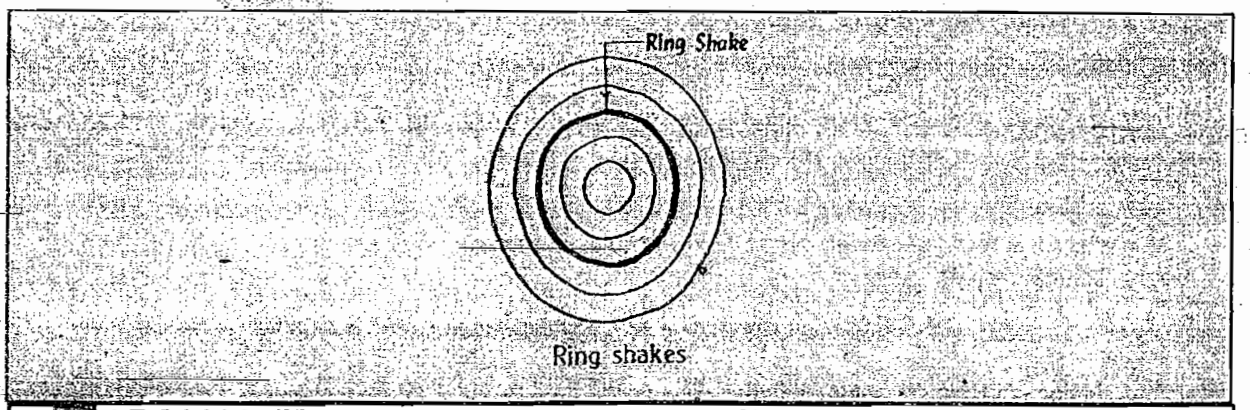
- It appears as curved split which partly or wholly separates annual rings from one another.
- It is caused due to excessive frost action on the sap present in the tree, especially when it is young.

(iii) Start shake :

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

(iv) Ring shakes :

- When cup shakes cover the entire ring, they are known as the ring shakes.



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IES/GATE/PSUs
Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
Phone: 011-41013406, 7838813406, 9711853908

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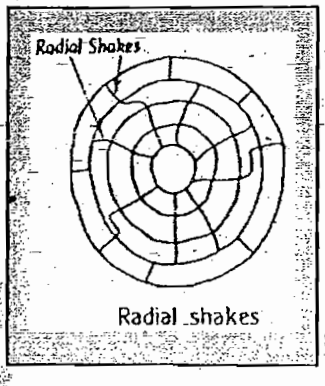
(v) Radial Shakes :

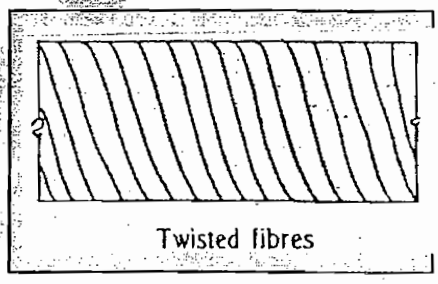
- These are similar to star shakes. But they are fine, irregular and numerous.
- It usually occur when tree is exposed to sun for seasoning after being felled down.
- It run for a short distance from bark towards the centre, and follow direction of annual ring and finally run towards pith.



Radial shakes

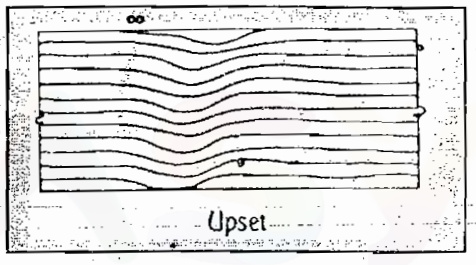
(vi) Twisted Fibres :

- It is also known as the wandering hearts and caused by twisting of young trees by fast blowing wind.
- Fibres of wood are twisted in one direction.
- Timber with twisted fibres is unsuitable for sawing. It can however be used for posts and poles in an unsawn condition.


Twisted fibres

(vii) Upsets :

- These are also known as the ruptures and they indicate the wood fibres which are injured by crushing or compression.
- Upsets are mainly due to improper felling of tree and exposure of tree in its young age to fast blowing wind.

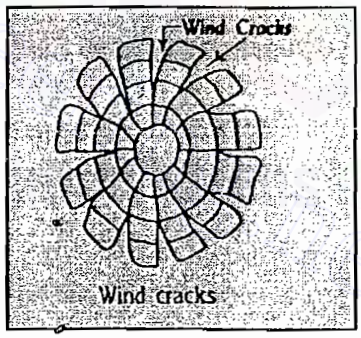

Upset

(viii) Water stain :

- Wood is sometimes discoloured when it comes into contact with water. This is known as the water stain and this defect is usually found in converted timber.

(ix) Wind Cracks :

- If wood is exposed to atmospheric agencies, its exterior surface shrinks. Such a shrinkage results into cracks as figure and these are called as the wind cracks.



Wind cracks

Defects Due to Seasoning

Defects occurring in timber due seasoning process is as follows.

(i) ***Bow :*** It is a curvature of the timber in the direction of its length.

(ii) ***Cup :*** A curvature in the transverse direction of the timber

(iii) ***Twist :*** It is a spiral distortion along the length of the timber.

(iv) ***Spring :*** It is a curvature of the timber in its own plane.

(v) ***Case hardening :*** It is due to the unequal drying of the exterior surfaces under compresion and the interior surfaces under tension due to rapid drying. This happens at heavily loaded bottom stacks kept for seasoning.

(vi) ***Split :*** It is separation of the fibres along the grainand extends from one end of the plank to the other.

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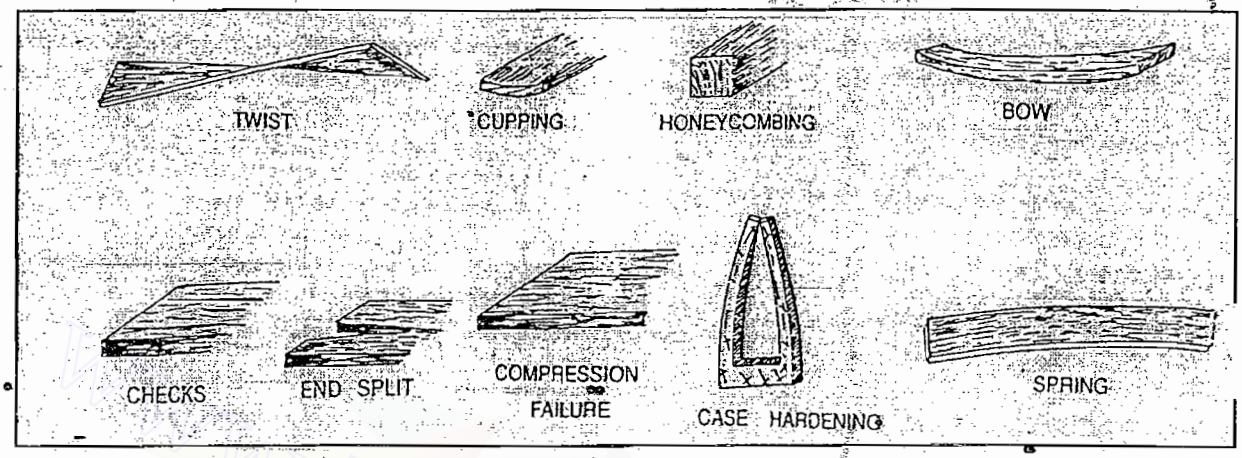
(vii) ***Honey combing :*** It is separation of the fibres in the interior due to drying stresses.

(viii) ***Shakes :*** These are as explained before.

(ix) ***Check :*** A check is a crack which separates fibres of wood due to rapid drying. It does not extend from one end to the other.

(x) ***Collapse :*** Due to uneven shrinkage, the wood sometimes flattens during drying. This is known as the collapse.

(xi) ***Wrap :*** When a piece of timber has twisted out of shape it is said to be wraped.



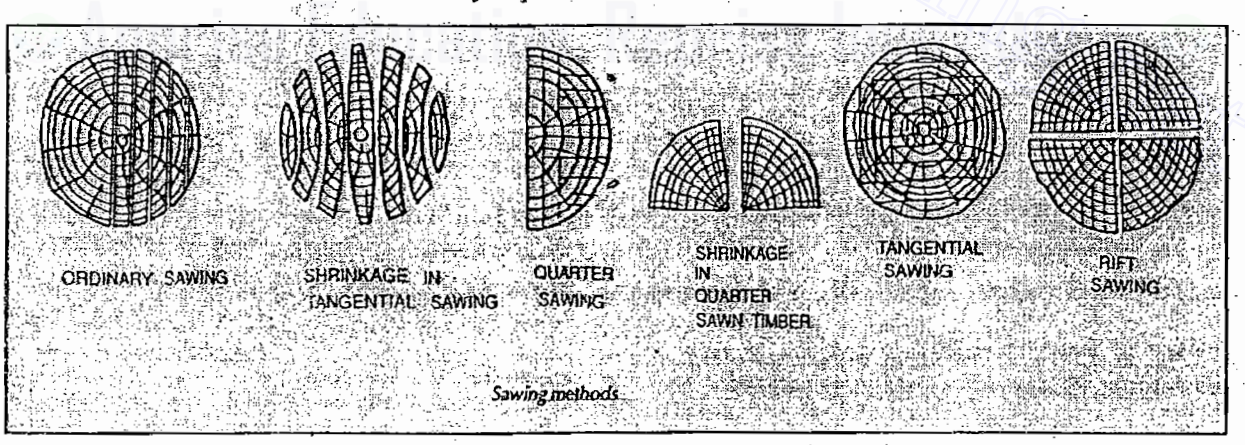
SAWING OF TIMBER

Methods of sawing are: (i) *ordinary sawing,* (ii) *tangential swaing,* (iii) *radial sawing,* (iv) *quarter sawing or rift sawing,* and (v) *combination sawing.*

Ordinary or Flat Sawing

- It is a very easy and quick method of sawing but is not economical. Log is moved backward and forward on because a saw which cuts parallel slices or planks and different thickness can be obtained by varying the width of cutting.

  Planks are liable to warp and twist as a result of unequal shrinkage central portion will be heartwood bound on the ends by sapwood.



Sawing methods

Tangential Sawing

- Cutting is tangential to the annual rings and at right angles to the medullary rays. Since the rays are cut, the sections are weak.
- The planks warp on drying more in the form of a cup. It cannot be polished evenly.

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Radial Sawing

- Sawing is done parallel to the rays and perpendicular to the rings. This is a better method of sawing and is suitable for floor boards, etc. as the wearing is uniform.
- Radially sawn timber shrinks and warps less than the ordinary sawn planks.
- Planks are ordinarily used for high class work.

Quarter or Rift Sawing

- In this method the log is first cut into quadrants. Each quadrant is further be sawn by plain, tangential or radial sawings.
- Quarter sawn wood wears better and shrinks more evenly.

Combination Sawing

- There are basically two methods of sawing, namely,
  (i) radially and
  (ii) at right angless to this.
- Whatever may be the particular name given to the sawing method, flat sawing is the name given to any method in which the rings make with the face an angle less than 45° and quarter sawing is the name given when this angle is more than 45°.

DECAY OF TIMBER

- Timber is said to be decayed when it is detoriated and looses it value as an engineering material.
- Timber does ot detoriate by natural, physical or chemical changes or by pure againg. It is affected by destructive elements, such as weathering chemical attack, fungi, insect or rodents.
- Various causes and situation cousing decay of timber are as below:
  (a) Alternate wet and dry conditions,
  (b) Bad stacking or storage of timber,
  (c) Fungi for developing diseases in timber such as blue stain, brown rot, dry rot, heart rot, sap stain, wet rot and white rot,
  (d) Bad seasoning,
  (e) Insects such as beetles, marine borers, termites, etc.,
  (f) Timber kept in contact with damp wall, damp earth, etc.,
  (g) Shocks or impacts received during young age from natural forces such as fast blowing wind, etc.,
  (h) Using timber without taking out sap wood from its structure,
  (i) Using seasoned timber without applying suitable preservative on its surface,
  (j) Using unseasoned wood with the application of protective coat of paint or tar.

PRESERVATION OF TIMBER (IS:401)

- The preservation of timber is carried out to achieve the following three objects:
  1. Increase the life of timber.
  2. Make the timber durable,
  3. Protect the timber structures from the attack of destroying agencies such as fungi insects, etc.

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Requirements of Good Preservatives

1. It should be strongly toxic to insects, fungi, etc.
2. It should penetrate easily into the timber.
3. It should not be soluble in water nor should it change in composition under ordinary climatic conditions.
4. It should cover a large surface area with a comparatively small quantity of the preservative.
5. It should have no destructive affect on the strength of the timber.
6. It should be harmless to human beings.
7. It should not cause timber more inflammable.
8. It should be non-corrosive to metals.
9. It should be pleasant in colour and give an attractive appearance to the wood work.
10. It should be highly resistant to water and dampness.
11. It should be economical and available readily.

Type of Preservatives

Preservatives commonly used for preservation of timber are:

(a) Ascu treatment (b) Chemical salts (c) Coal tar

(d) Creosote oil (e) Oil paints (f) Solignum paints.

(a) *Ascu Treatment*

- Ascu is special preservative which is developed at the Forest Research Institute, Dehradun.
- It composition is as below
  - 1 part by weight of hydrated arsenic pentoxide, (As_2O_5, $2H_2O$)
  - 3 parts by weight of blue vitriol or copper sulphate, ($CuSO_4$, $5H_2O$)
  - 4 parts by weight of potassium dichromate, ($K_2Cr_2O_7$) or sodium dichromate ($Na_2Cr_2O_7$, $2H_2O$)
- These materials are available in powder form.
- For preperation of solution six parts by weight of ascu is mixed in 100 parts by weight of water.
- Solution is then sprayed or applied on timber surface.
- This preservative gives timber protection against the attack of white ants.
- Surface treated with this preservative can be painted, polished, varnished or waxed.
- This solution is odourless.

(b) *Chemical Salts*

- These are water-borne preservatives and they are mostly dissolved in water.
- For example copper sulphate, mercury chloride, sodium fluoride and zinc chloride.
- Solution prepared from these salts are applied on the timber surface.
- These preservatives are odourless and non-inflammable.
- Surface treated by these chemicals can be painted or varnished after drying.
- These preservatives have good penetration and the timbers treated with these preservatives will show an immediate increase in weight of 2400 to 4800 N per m^3.

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(c) *Coal Tar*

- Timber surface is coated with hot coal tar (Because coal tar becomes workable when heated) with the help of brush, and this process is known as the tarring.
- Coal tar is fire resistant.
- Coal tar has unpleasant smell, appearance and it makes timber unsuitable for painting.
- Therefore tarring is adopted for frames of doors and windows, rough timber work, etc. and is found to be most useful for parts embeded in ground because of its cheapness and effective resistance.

(d) *Creosote Oil*

- Coating of timber surface with creosote oil is known as the creosoting or Bethel's method of preservation of timber.
- Creosote oil is obtained by distillation of tar.
- Creosoting is carried out as follows:
  (a) Timber is throughly seasoned and dried.
  (b) Then placed in an air tight chamber.
  (c) Air is pumped out from the chamber.
  (d) Creosote oil is then pumped under high pressure of about 0.70 to 1N/mm^2 and a temperature of about 50°C.
  (e) After a period of about 1 to 2 hours, when timber has sufficiently absorbed creosote oil, it is taken out of chamber.
- Creosote oil is one of the best antiseptic i.e. it is poisonous for wood-attacking fungi, weakly affected by water, neither volatile nor hygroscopic, harmless to wood or metal, inflammable, with an uppleasant odour and having low wood-penetrating ability to the extent of 1 mm to 2 mm only.
- Creosoting doubles the life of timber and it is generally adopted for piles, poles, railway sleepers, etc.
- Creosote oil should not be used for interior surfaces of dwelling houses, foodstuff-storage premises, in underground installations and near inflammable surface as at is highly toxic in nature and gives out highly unpleasant smell.

(e) *Oil Paints*

- Seasoned timber surface is coated with 2 or 3 coats of oil paint. Otherwise sap will be confined and it will lead to the decay of timber.
- Oil paints preserve timber from moisture and make it durable.

(f) *Solignum Paints*

- These paints preserve timber from white ants as they are highly toxic in nature.
- They can be mixed with colour pigments and applied in hot state with the help of brush.
- Timber surface may therefor be given the desired colour or appearance.

Methods of Treatment (IS : 401)

(a) *Surface Application*

- This is done either by brushing, spraying or dipping in the preservative solution for a short period.

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- For this treatment, round timber should be debarked thoroughly.
- At least 2 coats should be applied, second and subsequent coats being applied the after the first coat has dried or soaked into the wood.
- Surface treatment does not give surface absorption and is limited to treatment at site or for retreatment of cut surface.

(b) *Soaking*

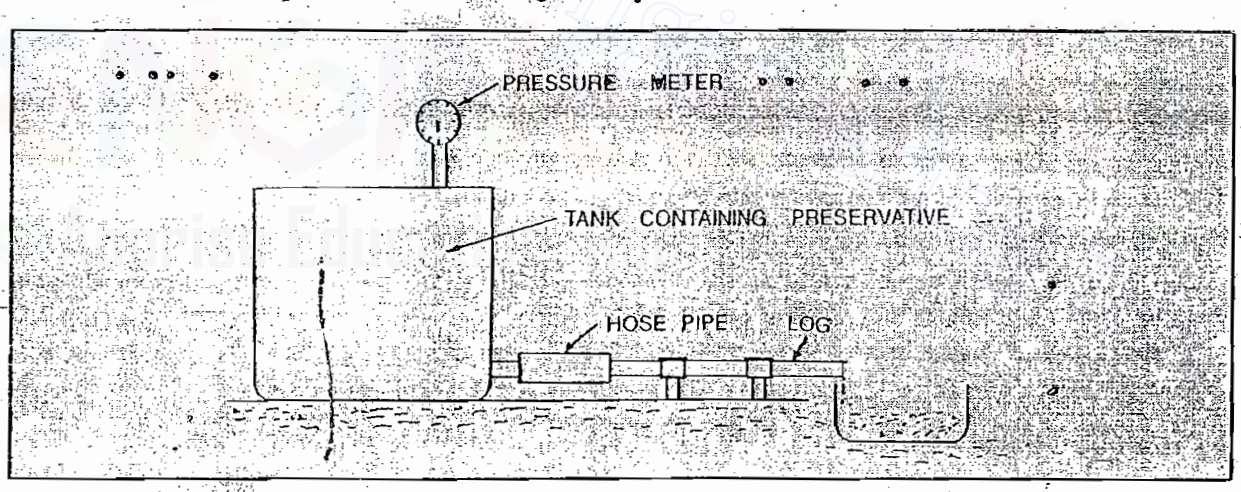
- Timber is debarked thoroughly and submerged in the preservative solution for a sufficiently long period till the required absorption is obtained.

(c) *Hot and Cold Process*

- Timber is kept submerged in the preservative solution which is maintained at a temperature of about 90°C for a suitable period depending upon the charge.
- During the heating period, air in the timber expands and is partially expelled.
- Then it is allowed to cool till the required absorption of the preservative is obtained.
- It should be noted that absorption takes place during cooling as during cooling, a partial vacuum is created which sucks in the presertvative.
- This method ensures sterilization of the timber against fungi and insects.
- If pressure treatment is not feasible then this method is suitable for all sapwood and easily treatable heartwood.

(d) *Boucherie Process*

- Sapwood of all green timbers with the bark on can be carried out with any of the inorganic water soluble preservatives.
- Treatment is carried out by attaching to the butt end of a pole a hose pipe connected to a reservoir of the preservative at a higher level.



- Pole is held in an inclined position at 45° to the horizontal with the butt end up.
- Due to hydrostatic pressure, the preservative displaces the sap in the wood which is then forced out at the narrow end.
- Treatment can be considered complete when the concentration of the preservative at the lower end is the same as that in the reservoir.
- Treatment can be speeded up by applying a pressure on the surface of the preservative in the reservoir.
- This method is also suitable for treating bamboo.

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(e) *Diffusion Process*

- Diffusion process can be done as below:
  (a) Momentary dipping of timber in concentrated solution and close stacking under cover.
  (b) Prolonged immersion in dilute solution and close stacking under cover.
  (c) Application of a preservative paste over all the surfaces of the timber and then close stacking under cover.
  (d) Injecting of the paste into timber through incisions spaead on the surface.
- This method is suitable in the case of timbers which are difficult to impregnatie under dry conditons and also where there is danger of the timber getting deteriorated during air seasoning.
- Principle of this method is that the inorganic toxic elements diffuse into timber from the place of application at high concentration to other zones through the medium of water contained in timber.
- With sufficient timber, uniform and complete absorption can be attained.
- Depth of penetration and amount of absorption in the diffusion process depends upon the concentration of the preservative, period of diffusion, species of timber, moisture contents, etc.

(f) *Pressure or Pneumatic Processes*

- It is a commercial process in which a large quantity of timber is treated.
- Large metallic drums are employed into which the charge of timber stacked on trolleys is taken in, drum is then closed and the process of treatment is started.
- Various pressure processes may differ in detail but are basically of two types.

(a) *Full cell Process or Bethelprocess :*

- It is essentially a pressure process and is used when maximum absorption of the preservative is desired. The timber charge is introduced into the cylinder. The door is tightly closed and then a vacuum of at least 560 mm of mercury is created and maintained for half an hour to remove as much air as possible from the wood cells.
- At the end of the vacuum period, the preservative is introduced into the cylinder, with the vacuum pump working. When the cylinder has been filled with the preservative, the vacuum pump is stopped and the cylinder is subjected to an antiseptic pressure of 0.35 to 1.25 N/mm^2 depending on the species, size, refractory nature of timber, etc. to inject the preservative into the timber. The pressure is held until the desired absorption is obtained.

(b) *Empty Cell Processes :*

Are also known as *pressure processes* and are aimed at a maximum penetration of the preservative with a minimum net retention.

(i) *Lawry Process*

- In this process cylinder is loaded with timber and closed, followed by filling with the preservative. An antiseptic pressure of 0.35 to 1.25 N/mm^2 depending on the timber species, size, etc. is applied until the required absorption is obtained.
- Pressure is released when a certain part of the preservative injected into the timber is expelled due to the expansion of the entrapped air in the cells.

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(ii) Rueping Process

- In this process, the cylinder is charged with timber and closed. An air pressure of 0.175 to 0.5 N/mm² is applied for a specified period depending upon the sapwood content of the timber and is maintained during the subsequent stage of filling up the cylinder with the preservative.
- When the cylinder is filled, an antiseptic pressure of 0.5 to 1.25 N/mm² depending on species, size, etc. is applied until the desired absorption is obtained. This process is specially recommended for treating timber of mixed species and timbers containing sapwood and heartwood.

(g) Charring

- This is very old method and as such no preservative is used in this method.
- Surface to be charred is kept wet for about half an hour and it is then burnt upon a depth of about 15mm over a wood fire.
- Charred portion is then cooled with water.
- Due to burining, a layer of coal is formed on the surface. This layer is not affected by moisture and it is not attacked by whilte ants, fungi, etc.
- Disadvantages of this method are:
  - (*a*) Charred surface becomes black in appearanced and hence it cannot be used for exterior wortk.
  - (*b*) Loss of strength of timber as the cross-section is reduced due to charring.
- Process of charring is genrally adopted for lower ends of posts for fencing, telephone, etc. which are to be embedded in the ground or to be inserted in moist soil.

FIRE RESISTANCE OF TIMBER

- Structural elements made of timber ignite and get rapidly destroyed in case of fire.
- But fire resistant characteristics of timber are better than steel which buckle and collapse much earlier than wood work.
- Timber above thickness 12mm, cannot support self sustained combustion and continoues to be burn only when external heat is supplied.
- Timber cannot be made fire proof, can only be made fire resistant by following chemical method.

Application of Special Chemicals

- Timber surface is coated with the solution of certain chemical,
- It is observed that two coats of solution of borax or sodium arsenate with strength of 2 % are quite effective in rendering the timber fire-resistant.
- These special chemicals are known as the fire protection compounds or antipyrings and they are more reliable.
- Temperature rises, they either melt or give off gases which hinder or forbid combustion.
- When the wood is treated with antipyrine, it does not inflame even at high temperature, but it merely smopulders i.e. burns slowly without flame.

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- Antipyrines containing salts of ammonium or boric and phosphoric acids are considered to be the best in making the timber fire-resistant.

Sir Abel's Process

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

Sodium silicate	56 g
Water	50 g
Kaolin	75 g

SEASONING OF TIMBER

- Seasoning is the process of reducing the moisture content (drying) of timber in order to prevent the timber from possible fermentation and making it suitable for use.
- Seasoning does not make timber safe from all destructive agencies, it is a prime process before timber can be put to use.
- During seasoning remaining moisture, which cannot be extracted, is uniformly distributed throughout the mass. If drying is irregular, the shrinkage of timber will also be irregular and it will set up internal stresses between the fibres.
- When these stresses become excessive and are capable of overcoming the cohesion of fibres, the timber warps and the shakes are formed.
- Seasoned timber should be protected from exposure to the rain and excessively high humidity.

OBJECTIVE OF SEASONING

(i) Reduce the shrinkage and warping after placement in structure.
(ii) Increase strength, durability and workability.
(iii) Reduce its tendency to split and decay.
(iv) Make it suitable for painting.
(v) Reduce its weight.
(vi) Make timber burn readily, if used as fuel.

METHODS OF SEASONING

- Seasoning methods can be basically classified into two groups, namely:
  1. Natural Seasoning
  2. Artifical Seasoning.

Natural Seasoning

- Log of wood is sawn into plank of convenient sizes and stacked under a covered shed in cross-wise direction in alternate layers, so as to permit free circulation of air.
- Duration for drying depends upon the type of wood and the size of planks.
- Rate of drying is very slow.

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- Air seasoning reduces the moisture content of the wood to 12-15%.
- It is used very extensively in drying ties and the large size structural timbers.

Advantages of Natural Seasoning

Following are the advantages of the natural seasoning:

(i) Depending upon the climatic conditions, the moisture content of wood can be brought down to about 10 to 20%.

(ii) Does not required skilled supervision.

(iii) It is uneconomical to provide artifical seasoning to timber sections thicker than 100mm, as such section dry very slowly. Therefore thicker timber sections are usually seasoned by the process of air seasoning.

iv) It is cheap and simple.

Disadvantages of Natural Seasoning

Following are disadvantages of natural seasoning.

(i) As the process depends on the natural air it becomes difficult to control it.

(ii) Drying of different surfaces may not be even and uniform.

(iii) If ends of thick sections of timber are not protected by suitable moisture-proof coating, there are changes for end splitting because the ends of such timbers dry rapidly in comparison to the central portions.

(iv) If not properly attended, th fungi and insects may attack timber during the process of seasoning and may thereby damage it.

(v) Moisture content of wood may not be brought down to the desired level.

(vi) Space required for this process will be more as timber will have to be stacked or stored for a sufficiently long time.

Artifical Seasoning

- Artifical methods are adopted for faster drying and to attain desired moisture content during artificial seasoning.
- Drying conditions required for different timber are different by application of artificial seasoning methods it is possible to provide condition suited to each species.

Methods of Artifical Seasoning

(a) Boiling

- In this method of timber is immersed in water and water is then boiled.
- It is a very quick method.
- Timber is thus boiled with water for about three to four hours then dried very slowly under a shed.
- Periods of seasoning and shrinkage are reduced by this method, but it affects the elasticity and strength of wood.

(b) Chemical Seasoning

- Chemical seasoning or salt seasoning.
- In this method, the timber is immersed in a solution of suitable salt and then taken out and seasoned in the ordinary way.
- Interior surface of timber dries in advance of exterior one and changes of formation of external cracks are reduced.

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(c) *Electrical Seasoning*

- In this method, use of high frequency alternating currents is done.
- Timber when it is green, offers less resistance to the flow of electric current and resistance increases heat.
- It is the most rapid method of seasoning. but the initial and maintenance costs are such high that it bcomes unceonomical to season timber on commercial base by this method.

(d) *Kiln Seasoning*

- In this method, the drying of timber is carried out inside an airtight chamber of oven.
- Process of seasoning is as follows:
  - (i) Timber is arranged inside the chamber such that spaces are left for free circulation of air
  - (ii) Air which is fully saturated with moisture and whcih is heated to a temperature of about 35°C to 38°C is then forced inside the chamber by suitable arrangement.
  - (iii) Forced air is allowed to circulate round the timber pieces. As air is full saturated with moisture, the evaporation from the surfaces of timber peeces is prevented. The heat gradually reaches inside the timber pieces.
  - (iv) Relative humidity is now gradually reduced.
  - (v) Temperature is then raised and maintained till the desired degree of moisture content is attained.

Comparision between natural seasoning and kiln seasoning.

S.No.	Item	Natural seasoning	Kiln seasoning
1.	Moisture content	Difficult to reduce the moisture content below 15 to 8%	Moisture content can be reduced to any desired level
2.	Nature	Simple and economical	Expensive and quite technical
3.	Quality of timber	Air seasoned timber is more liable to the attacks of insects and fungi.	Kiln seasoned timber is less liable to the attacks of insects and fungi
4.	Space	Requires more space for stacking.	Requires less space for stacking.
5.	Speed	Slow process.	Quick process
6.	Strength	Gives stronger timber.	Gives a little weaker timber.

- ***Timber drying kilns are of basicly two type:***

  (i) Progressive kiln (ii) Compartment kiln

Progressive Kiln

- In these kiln a carriage with timber sections, travels slowly from one end to the other and in doing so, it gets seasoned.
- Hot air is supplied from the discharging end such that temperature is less at the charging end and it increases towards the discharging end.
- It is used for seasoning timber on a large scale. If not properly monitored the drying in this kiln may prove to be unsatisfactory.

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- These kiln are also known as stationary kiln.
- In these kiln process of seasoning is carried out in a single compartment only and drying operations are adjusted as drying proceeds.
- This kiln is adopted for seasoning timber which requires a close control of humidity and temperatue. It gives better results.

Note:

Although kiln seasoning is costly, but it provides will seasoned timber as it controls three important conditions (a) circulating air (b) Relative humidity (c) Temparature.

Water Seasoning

- In this method logs of woodare kept completely immersed in running stream of water, with their larger ends pointing upstream.
- Therefore the sap, sugar, and gum are leached out and are replaced by water.
- 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.

Advantages of artificial seasoning over natural seasoning.

1. Defect such as shrinkage, cracking and warping are minimized.
2. Drying is controlled and there are practically no chances for the attack of fungi and insects.
3. Drying of different surfaces is even and uniform.
4. It reduces the period of seasoning.
5. There is better control of circulation of air, humidity and temperature.
6. Wood becomes more suitable for painting, gluing, etc.
7. Wood with desired moisture content is obtained by the artifical seasoning.

STORAGE OF TIMBER

- Structural timber should be properly stored to avoid any further development of defects.
- For the purpose of storage, suitable stack of timber pieces are formed.
- Length of stack depends on length of timber pieces. Its width and height are usually limited to about 1.50m to 2m respectively.
- Material is arranged in layers and the layers are separated by wooden battens which are known as the crossers or spacers.
- Stack should be protected from direct sun, dry wind and rain. If necessary, a sloping roof of suitable material may be provided over the stack.

  (*a*) In each layer, an air space of about 25mm should be maintained between adjacent membners.

  (*b*) The ends of all members should be coated with suitable material to prevent end-cracking

  (*c*) The longer pieces should be placed in bottom layers and the shourter pieces should be placed in top layers.

  (*d*) Platform of stack should be made at least 150mm higher than ground.

  (*e*) There should be a minimum distance of at least 300mm between adjacent stacks.

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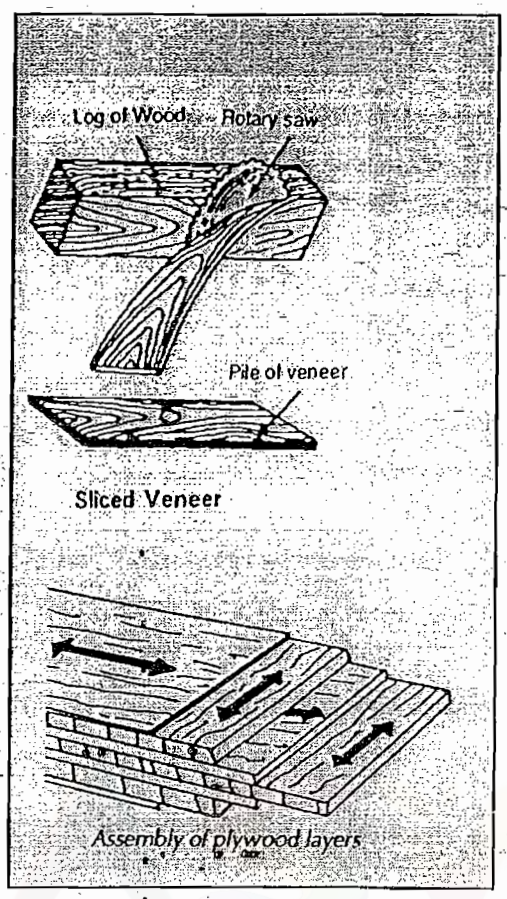
WOOD PRODUCTS

1. Verneers

- Verneers are thin sheets of wood of thickness varying from 0.4 to 0.6mm, but is no case more than 1mm.
- They are obtained by rotating a log of wood against a sharp knife of rotary cutter or saw veneer4s after being removed are dried in kilns to remove moisture.
- Verneers are used to produce plywood, batter boards and laminboards.
- Verneers may be glued to inferior wood to improve its appearance.



2. Plywood

- A wood panel glued under-pressure from an odd number (usually 3 to 13) of layers/ piles of veneers is known as plywood.
- Outer most veneer sheets in a plywood panel are called/ faces.
- Interior ply/piles which have their grain directrions parallel to that of the faces are termed as core/ centre.
- Other piles which have grain directions perpendicular to that in the face are termed as cross bands.
- Plywood can be classified upon direction of grains in the piles and on the type of adhesive used.
- Normally the alternate plies are oriented at 30° or 60° in star plywood.
- Faces are arranged with the grain at 45° to that of the centres in diagonal plywood.
- Piles bonded together with water soluble glues suchas casein glue. interior grade plywood is obtained
- When piles are bonded with phenol formaldehyde adhesive it is identified as exterior grade plywood which is completely water proof.

Thickness of Plywood Boards ((S: 303 and 10701)

Board	Thickness (mm)	
	General Purpose	Structural purpose
3 ply	3, 4, 5, 6	4
5 ply	5, 6, 8, 9	6, 9
7 ply	9, 12, 15, 16	12, 16
9 ply	12, 15, 16, 19	16, 19
11 ply	19, 22, 25	19, 25
Above 11 ply	On order	19, 25

- Structural plywood panels are available in following sizes.

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2400 × 1200 mm, 2100 × 1200mm, 1800 × 1200mm, 2400 × 900mm, 2100 × 900mm, 1800 × 900mm.

Advantages

(i) It has good strength both along as well as across the grains.

(ii) Wood shrinks or swells more across the grains. Since plywood has cross-grained construction, the tendency to shrink or swell is reduced.

(iii) It has better splitting resistanced due to the grains in adjacent veneers in cross-direction as such nailing can be done very safely even near the edges.

(iv) Plywood can be curved into desired shapes.

Uses

Extensively used for partitions, ceilings, doors, concrete form work, plywood boards, lamin boards and block boards etc.

Fiber Board

- These are rigid boards also known as pressed wood or reconstructed wood.
- These board are built up of felting from wood or vegetables (wood waste, waste paper, agriculature waste etc.
- Length variees from 3–4.5m, width 1.2–1.80m and thickness 3–12mm.
- Depending upon their form and composition, the fibreboards are classified as insulating boards, medium hard boards, hard boards, superhard boards and laminated boards.
- Fibreboards form an ideal base for practically all types of decorative finishes such as distemper, oil paint, etc.
- Hard boards are also suitable for polish and varnish.
- *Uses :* They are widely used for wall and ceiling cladding, partitions, doors, perforated acoustic tiles, railway carriages, bus bodies, etc.

Praticle Boards or Chip Boards

- Wood and wood waste is first converted into small chips by high-speed chippers.
- Moisture content of the chips are then reduced to about 15% by drying in automatic driers.
- Chips are then sprayed with some glueing material, usually synthetic adhesives like phenol formaldehyde. Then chips coated with adhesive are then spread to form mats. Usually a three layer particle board is made.
- Different species of timber for the outer and inner layers.
- The particles in the form of a mat are pressed in a hydraulic press in the presence of heat and moisture.
- Length varies from 0.9 – 4.85m, width 0.45 – 1.85m and thickness 6–40mm.
- Moisture content of chips is reduced to a certain percentage and then some gluing material, usually phenol formaldehyde is sprayed.
- Chips are then spread to form a mat and then pressed in a hydraulic press in presence of heat and moisture.
- Particle boards, wavoid wastage of timber as in its making the entire volume of the fallen tree can be utilized.
- Trees used for making particle boards are eucolyptus, subabool, and rubber wood, and waste of saw mill.
- Boards provide dimensional stability, smooth uniform surface, and no difficulty in nailing.
- Particle boards are extensively used for partitions doors, furniture making, etc.

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Institute for Engineers
IES/GATE/PSUs
Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
Phone: 011-41013406, 7838813406, 9711853908

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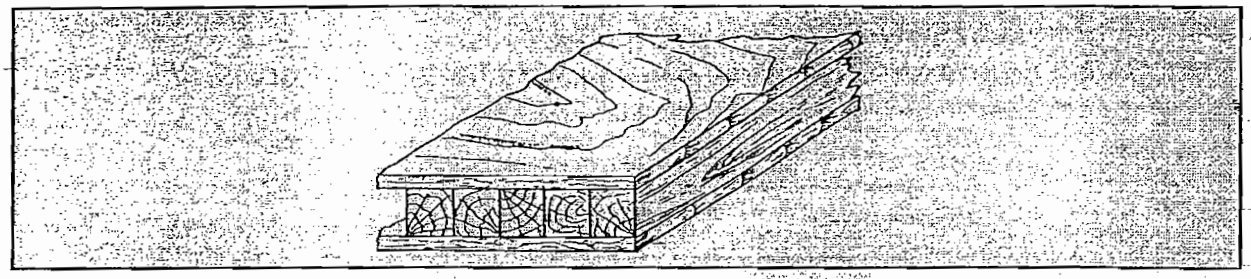
Block Board

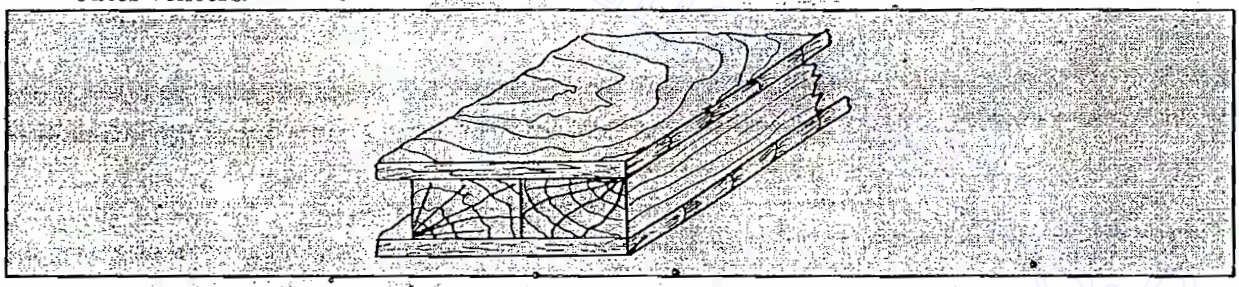
- These are boards having a core made up of strips of wood each not exceeding 25mm in width, laid separately or glued or joined to form a slab which is glued between two or more outer veneers with the direction of the core blocks running at right angles to that of the adjacent outer veneers.



- Veneers used for cross bands and faces are rotary cut or sliced and should be resonable smooth.
- Cross band thickness varies between 1 – 3mm and face veneers between 0.5 to 1.5 mm.
- These are available in thickness of 12, 15, 19, 25, 30, 35, 40 and 50.
- Bolck board are available in sizes 2400 × 1200, 2100 × 1200, 1200 × 900, 1800 × 1200, 1800 × 900mm.
- Block boards are extensively used for construction of railway carriages, bus bodies, marine and river crafts and for furniture making, partitions, panelling, prefabricated houses, etc.

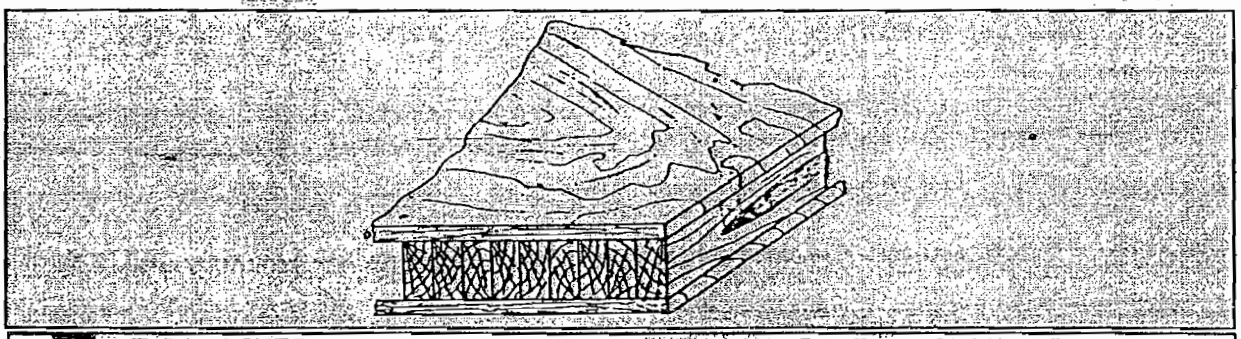
Batten Board

- It is a board having a core made up of strips of wood usually 8 cm wide, each laid separately or glued or otherwise joined to form a slab which is glued between two or more outer veneers with the direction of the grain of the core running at right angles to that of the adjacent outer veneers.



Lamin Board

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



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Institute for Engineers
IES/GATE/PSUs
Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org. E-mail: ies_master@yahoo.co.in
Phone: 011-41013406, 7838813406, 9711853908

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Batten

It is a timber piece whose breadth and thickness do not exceed 50 mm.

End

This is a short piece of batten, deal, scantling, etc.

Log

It is the trunk of tree obtained after removal of branches.

Plank

It is a timber piece with parallel sides. Its thickness is less than 50mm and its width exceeds 50 mm.

Pole

It is a sound long log of wood. Its diameter does not exceed 200mm. It is also known as a spar.

Quartering

It is a square piece of timber, the length of side being 50 mm to 150mm.

Scantling

This is a timber piece whose breadth and thickness exceed 50mm, but are less than 200mm in length. These are the pieces of miscellaneous sizes of timber sawn out of a log.

IMPORTANT TIMBER AND THEIR USES

Name	*Property*	*Uses*
Babul	It is strong, hard, very durable and tough. It takes up a good polish.	It is used for bodies and wheels of bullock carts, agriculatural instruments, tool handles, well kerbs, sugarcane and oil presses, house and boat building, etc.
Bakul	Its colour is reddish brown. It is close-grained, very hard, strong, durable and tough.	It is used for making cabinets, building and bridge construction piles etc.
Bamboo	It is an endogenous tree. It is flexible, very strong and durable.	It is used for scaffolding, thatched roofs, rafters, temporary bridges fancy goods, etc.
Benteak	It is strong and takes up a smooth surface.	It is used for building construction, boat construction, furniture, etc.
Casuaring	Its colour is reddish brown. It grows straight. It is strong and fibrous.	It is used for scaffolding, posts for temporary structures, etc.

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Deodar	It is the most important timber tree providing soft wood. It is moderately strong.	It is used for making cheap and rough furniture, railway carriages railway sleepers, packing boxes, structural work.
Hopea	Its colour is light to deep brown. It is extremely strong and tough. It is difficult to work. It is durable and not llikely to be damaged by white ants.	It is used for ordinary house construction, railway sleepers, piles, boat building, etc.
Iron Wood	It is durable. It is very hard and is not easily worked. It even resists penetration of nails.	It is used for ordinary house construction bridges, piles, agricultural instruments, railway wagons, railway sleepers etc.
Irul:	It is very hard, heavy and durable. It is difficulat to work, it requires slow and careful seasoning.	It is used for railway sleepers, agricultural instruments, paving blocks heavy construction etc.
Jarul	It is hard and durable. It can be easily worked. It takes a good finish. It resists the action of salty water.	It is used for house construction, boat building, railway carriages, cart making, scaffolding, agricultural tools, etc.
Kathal	Its colour is yellow to deep brown. It is heavy and hard.	It is used for piles, platforms of wooden bridges, door and window panels, etc.
Mahogany	Its colour is shning reddish brown. It takes a good polish. It is easy to work. It is durable under water.	It is used for furniture, pattern making, cabinet work, ornamental panelling, fancy goods, etc.
Mango	It is easy to work. It maintains its shyape well it is moderately strong.	It is used for cheap furniture, toys packing boxes, ship building cabinet work, panels for doors and windows, etc.
Mulberry	It is strong, tough and elastic. It takes up a clean finish. It can be well seasoned. It is turned and carved easily.	It is used for baskets and sport goods like hockey sticks, tennis rackets, cricket bats, etc.
Oak	It is strong and durable. It possesses straight silvery grains.	It is used for preparing the sport goods.
Palms	It contains ripe wood in the outer crust. It is fibrous.	It is used for furniture, roof covering rafters, joists, etc.
Pine	It is hard and tough except white pine which is soft. It decays easily.	It is used for pattern making, frames for doors and windows, paving material, etc. The white pine is used in the manufacture of matches.

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Red cedar	It is soft and even grained. It is durable in moist places and underwater. It takes a good polish.	It is used for furniture, door panels, well kerbs, piles, railway sleepers, bridge construction etc.
Rosewood or blackwood	It is dark in colour. It is srong, tough and close-grained. It is handsome and it takes up a high polish. It maintains its shape well.	It is used for furniture of superior quality, cabinet work, ornamental carvings, etc.
Sandal	Its colour is white or red. It gives out pleasant smell.	It is used for agricultural instruments, well kerbs wheels mallets fancy goods, boxes, etc.
Sissoo	It is also known as the shisham or tail. Its colour is dark brown. It is strong and tough. It is durable and handsome. It maintains its shape well. It can be easily seasoned. It is difficult to work, but it takes a fine polish.	It is used for high clas furniture, plywoods bridge piles, sport goods, railway carriages, etc. It is a very good material for decorative works and carvings.
Spruce	It resists decay. It is not affected by the attack of marine borers. It is liable to shrink, twist and warp.	It is used for piles under water, aeroplanes, etc.
Teak	It is moderately hard. It is durable and fire-resistant. It can be easily seasoned and worked. It takes up a good polish. It is not attacked by white ants and dry rot. It does not corrode iron fastenings. It shrinks little. It teak is a very durable timber.	It is used for house construction, railway carriages, flooring, structural work, ship building, furniture, mallets, agricultural instruments, well kerbs, piles, etc. Its use is limited to superior work only as it is comparatively very costly.

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Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
Phone: 011-41013406, 7838813406, 9711853908

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CONVENTIONAL QUESTIONS

1. Explain the treatments of timber by Creosoting and by the Ascu Process. (1987)
2. Write in brief the characteristics of a good timber. What are the important requirements of a good preservative for timber? (1988)
3. What is the necessity for seasoning of timber? Briefly describe one method of seasoning. (1990)
4. Briefly describe the following defects in timber, giving neat sketches knots. Cup and ring shakes. Star shake. Heart shake. (1992)
5. List out the characteristics of good timber. What is meant by 'seasoning of timber'? Why is it necessary: mention the different methods of seasoning of timber. (1993)
6. Indicate the ingredients and their proportions in which they are used in Ascu process for the tratment of timber. How is this treatment carried out? (1994)
7. What is decay in timber? How is it detected? How can the timber be guarded against decay? Name any two diseases of timber. (1995)
8. What is meant by the term; 'seasoning of timber' and 'preservation of timber'?
9. Name the various methods of applying preservatives to timber. Give a brief account of one method.
10. Explain the preservative treatment of timber indicating the types, characteristics and methods of applications of preservatives. (1998)
11. Explain the following :
    (i) Plywood
    (ii) Laminated board
    (iii) Battern
    (iv) Fibre board (2001)
12. Describe four common defects in the timber. (2003)
13. What is seasoning of timber and why is it done? Discuss in brief the different methods of seasoning timber. (2004)
14. Draw the related stress-strain curves for a timber member under tension, compression and bending parallel to the grains. Discuss the importance of compression test results. (2005)
15. Explain the methods of improving fire resistance of timber. (2006)
16. Write briefly about five methods of artificial seasoning of timber. (2007)
17. Give a short description of preservation of wood using various wood preservatives. (2008)
18. Draw a neat sketch of macrostructure of exogenous tee. (2009)
19. Draw neat sketches showing various types of shakes. (2009)
20. Why is seasoning of timber required? List out the methods of seasoning.
21. Write briefly on the composition and properties of refractory bricks. (2009)

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OBJECTIVE QUESTIONS

1. According to the relevant IS code, the weight of the timber is to be reckoned at a moisture content of
   (a) zero (b) 4%
   (c) 8% (d) 12%
2. The strength of timber is maximum when load applied as
   (a) parallel to grain (b) perpendicular to grain
   (c) inclined at 45° to grain (d) inclined at 60° to grain
3. Consider the following statements:
   Fibre saturation point in wood is reached when
   1. Free water is removed.
   2. Cell water is removed.
   3. Shrinkage of wood is rapid.
   4. Strength gain is rapid
   Which of these statements are correct?
   (a) 1, 2 and 3 (b) 1 and 2 only
   (c) 2 and 4 only (d) 1, 3 and 4
4. The expansion and shrinkage of plywood's are comparatively very low as
   (a) they are held in position by adhesives
   (b) the are glued under pressure
   (c) plies are placed at right angles to each other
   (d) they are prepared from veneers
5. Seasoning of timber is required to
   (a) soften the timber (b) harden the timber
   (c) straighten the timber (d) remove sap from the timber
6. Match **List-I** with **List-II** and select the correct answer using the codes given below the lists :

List-I	List-II
A. Deciduous	1. Soft wood
B. Conifer	2. Hard wood
C. Endogenous	3. Eucalyptus
D. Exogenous	4. Bamboo

Codes :

	A	B	C	D
A.	1	2	3	4
B.	2	1	3	4
C.	2	1	4	3
D.	1	2	4	3

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7. The modulus of elasticity of timber is about

(a) 0.5 to 1.0 × 10^4 N/mm^2 (b) 1.0 to 1.5 × 10^4 N/mm^2

(c) 1.5 to 2.0 × 10^4 N/mm^2 (d) 2.0 to 2.5 × 10^4 N/mm^2

8. During the conversion of timbor by sawing, in order to obtain strong timber pieces, the cuts should be made by

(a) ordinary sawing (b) tangential sawing

(c) quarter sawing (d) radial sawing

9. The moisture content in structural timber should be

(a) less than 5% (b) 5 to 10%

(c) 10 to 20% (d) 15 to 25%

10. Match **List-I** with **List-II** and select the correct answer using the codes given below the lists :

List-I

A. The innermost part or core of the stem of a tree

B. The vascular tissue which encloses the pith

C. A cellular tissue and woody fibre arranged in distinct concentric circles

D. The thin layer below the bark not converted into sapwood as yet

List-II

1. Transverse septa (medullary rays)
2. Annual rings
3. The cambium layer
4. The outermost cover or skin of the stem
5. Medulla (pith)

Codes :

	A	B	C	D
A.	2	5	3	4
B.	5	1	2	3
C.	4	3	2	1
D.	5	1	4	3

11. Consider the following statements:

1. Dry rot in sap wood is caused by fungal attack.
2. Brown rot in coniferous woods is a result of fungal attack.
3. Alternate wetting and drying of unseasoned timber causes 'powdery' form of decay in wood.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1 and 2 only

(c) 2 and 3 only (d) 1 and 3 only

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12. Consider the following methods of preservation of timber :
    1. Dipping
    2. Brushing or spraying
    3. Pressure impregnation

    The correct sequence in decreasing order of the effectiveness of these methods of preservation is

    (a) 1, 2, 3 (b) 2, 1, 3
    (c) 3, 1, 2 (d) 3, 2, 1

13. Radial splits in timber originating from 'bark' and narrowing towards the 'pith' are known as

    (a) heart shakes (b) star shakes
    (c) cup shakes (d) knots

14. The moisture content in a properly seasoned timber will be in the range of

    (a) 5% to 8% (b) 8% to 10%
    (c) 10% to 12% (d) 12% to 15%

15. On application of external stress on timbers, it behaves like

    (a) an elastic material (b) non-elastic material
    (c) viscoelastic material (d) non-viscoelastic material

16. The ratio of tangential shrinkage to radial shrinkage of wood due to reduction in moisture content is

    (a) in the range from 3.1 to 5.1 (b) in the range from 2 to 3
    (c) in the range from 1 to 12 (d) less than or equal to 1

17. The compressive strength in structural timer is minimum in a direction

    (a) parallel to the grains
    (b) perpendicular to the grains
    (c) along an axis inclined at 45° to the grains
    (d) along an axis inclined at 60° to the grains

18. The advantage in using plywood is that the

    (a) tensile strength is equal in all directions
    (b) higher tensile strength in longer direction
    (c) higher tensile strength in shorter direction
    (d) lower tensile strength in longer direction

19. Consider the following characteristics regarding timber:
    1. Stronger variety
    2. Ability to take very smooth finish
    3. Toughness
    4. Difficult to season

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Which of the characteristics is/are essential for timber to be used as beams?

(a) 1 only (b) 2 and 3

(c) 3 and 4 (d) 1 and 3

20. Timber can be made reasonably fire resistance by

(a) soaking it in ammonium sulphate

(b) coating with tar paint

(c) pumping creosote oil into timber under

(d) seasoning process

21. Consider the following methods of preservation of timber:

1. Pressure application
2. Brush application
3. Dipping
4. Open tank application

The correct sequence of these methods in the increasing order of their effectiveness is

(a) 1,3,4,2 (b) 3,4,2,1

(c) 2,3,4,1 (d) 4,2,1,3

22. Match **List-I** (Name of defect) with **List-II** (Definition) and select the correct answer using the codes given below the lists:

List-I

A. Cupping

B. Bowing

C. Checks

D. Knots

List-II

1. Caused by wood limbs encased by the wood of the free trunk
2. Caused by grain irregularities in the board and can be eliminated by proper stacking
3. Small cracks appearing at the ends of boards caused by too rapid drying
4. Unequal shrinking in the radial and tangential direction

Codes :

	A	B	C	D
(a)	1	2	3	4
(b)	4	3	2	1
(c)	1	3	2	4
(d)	4	2	3	1

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23. How is the process of treatment of wood using a preservative solution and forcing air in at a pressure designated?

(a) Rueping process (b) Lawry process

(c) Full cell process (d) Empty cell process

24. Consider the following statements:

1. Cambium layer is between sapwood and heartwood.
2. Heartwood is otherwise termed as deadwood.
3. Timber used for construction is obtained from heartwood.

Which of these statements is/are correct?

(a) 1,2 and 3 (b) 2 and 3 only

(c) 1 and 2 only (d) 2 only

25. Dry rot in timber is caused by

(a) lack of ventilation (b) lack of light

(c) lack of light (d) alternate wet and dry atmosphere

26. Wood is impregnated with creosote oil in order to

(a) change its colour (b) protect against fungi

(c) protect the annular layers (d) fill up the pores

27. Consider the following statements:

Hardest timber is obtained from the wood grown in

1. the moderately dry climatic regions
2. the Himalayan slopes
3. the open areas
4. the thin jungles

Which of these statements are correct?

(a) 1 and 3 (b) 1 and 4

(c) 2 and 3 (d) 2 and 4

28. Consider the following statements:

Dry rot in timber is due to

1. stacking wood in open areas
2. lack of ventilation
3. decomposition of sap
4. lack of preservatives

Which of these statements are correct?

(a) 1 and 2 (b) 1 and 3

(c) 2 and 3 (d) 3 and 4

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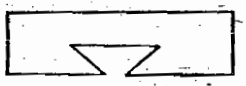
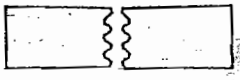
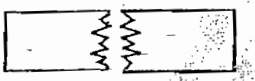
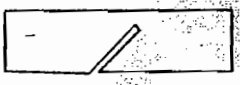
29. In static bending test Match **List-I** (Type of failure) with **List-II** (Figure) and select the correct answer using the codes given below the lists:

List-I	**List-II**
A. Simple tension	1. 
B. Cross grain tension	2. 
C. Splintering tension	3. 
D. Brash tension	4. 

Codes :

	A	B	C	D
(a)	1	4	3	2
(b)	4	1	3	2
(c)	4	1	2	3
(d)	1	4	2	3

30. Match **List-I** (Product) with **List-II** (Its use) and select the correct answer using the codes given below the lists:

List-I	**List-II**
A. Fibre board	1. Panelling
B. Heartwood	2. Insulation
C. Laminated timber	3. Scantling
D. Plywood	4. Arches/Trusses

Codes:

	A	B	C	D
(a)	3	2	1	4
(b)	3	2	4	1
(c)	2	3	4	1
(d)	2	3	1	4

31. Match **List-I** (term) with **List-II** (Brief discription) and select the correct answer using the codes given below the lists:

List-I

A. Heart shakes

B. Knot

C. Rot

D. Sap wood

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List-II

1. Disintegration caused by fungi
2. Outer layers of a log of wood
3. A branch base embedded in timber by natural growth
4. Cracks widest at centre and diminishing towards the outer circumference

Codes:

	A	B	C	D
(a)	1	3	4	2
(b)	4	2	1	3
(c)	1	2	4	3
(d)	4	3	1	2

32. Consider the following statements:

The disease of dry rot in timber is caused by

1. complete submergence in water
2. alternate wet and dry condition
3. lack of ventilation

Which of these statements is/are correct?

(a) 1 only (b) 3 only
(c) 2 only (d) 2 and 3

33. Consider the following statements:

Kiln seasoning of timber results in

1. reduced density
2. reduced life
3. dimensional stability

Which of these statements is/are correct?

(a) 1, 2 and 3 (b) 1 only
(c) 2 and 3 (d) 1 and 3

34. In a tree, the cambium layer is situated between

(a) the outer bark and inner bark
(b) the inner bark and sap wood
(c) the sap wood and heart wood
(d) the pith and heart wood

35. The timber preservative "creosote" belongs to the group of

(a) water soluble salts (b) organic solvent type
(c) tar oil type (d) inorganic solvent type

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36. Which one of the following is the most preferred wood for high quality and durable furniture?
(a) Sandal wood (b) Deodar wood
(c) Teak wood (d) Shisham wood

37. As a natural material, timber is which one of the following?
(a) Isotropic (b) Anisotropic
(c) Homogeneous (d) Heterogeneous

38. Shear strength of timber depends on which one of the following?
(a) Lignin with fibres (b) Medullary rays
(c) Heart wood (d) Sapwood

39. The defect which develops due to uncontrolled and non-uniform loss of moisture from wood is known as which one of the following?
(a) Knot (b) Shake
(c) Warping (d) Cross grain

40. What is the treatment for making timber fire-resistant?
(a) ASCU treatment (b) Abel's process
(c) Creosoting (d) Tarring

41. Match List-I (Wood element) with List-II (Description) and select the correct answer using the codes given below the

Lists-I

A. Pith
B. Sapwood
C. Heart wood
D. Cambium layer

List-II

1. Innermost portion of the tree
2. Inner annual rings surrounding the pith
3. Outermost annual rings
4. Thin layer of sap between sapwood and inner bark

Codes:

	A	B	C	D
(a)	1	3	2	4
(b)	2	4	1	3
(c)	1	4	2	3
(d)	2	3	1	4

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42. In respect of moisture content in wood, the fiber saturation point refers to which one of the following?

(a) Free water present in the cells

(b) Free water present in cell walls and cell cavities

(c) No moisture present in cell walls and cell cavities

(d) no free water exists in cell cavities but cell walls are saturated

43. The moisture content of timber used in building frames can be

(a) 2% to 5% (b) 8% to 12%

(c) 12% to 18% (d) > 20%

44. Match **List-I** (Disease of timber) with **List-II** (Effect of disease) and select the correct answer using the codes given below the lists:

List-I

A. Dry rot

B. Grey rot

C. Wet rot

D. White rot

List-II

1. Attack of sapwood by fungus
2. Damage to wood fibers due to chemical decomposition of wood
3. Destruction of cellulose of wood due to fungal attack
4. Destruction of lignin of wood due to fungal attack

Codes :

	A	B	C	D
(a)	1	3	2	4
(b)	1	4	2	3
(c)	2	3	1	4
(d)	2	4	1	3

45. What is the ratio of the elastic modulus of structural timber in longitudinal direction to that in the transverse direction?

(a) 1.2 to 1 (b) 1/10 to 1/20

(c) 1 to 2 (d) 10 to 20

46. What is the modulus of elasticity of standard timber (Group B) in (MN/cm^2)?

(a) 0.5 to 1.0 (b) 1.0 to 1.25

(c) 1.25 to 1.5 (d) 1.5 to 1.75

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The following items consists of two statements, one labelled as 'Assertion (A)' and the other as 'Reason(R)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes :

(a) Both A and R are true and R is the correct explanation of A

(b) Both A and R are true but R is not a correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

47. **Assertion (A):** Wooden window shutters should be fitted, leaving proper tolerances for dimensional changes.

Reason (R): Timber sections change in volume with change in seasons.

48. **Assertion (A) :** Timbers used for engineering construction are derived from deciduous trees.

Reason (R) : Deciduous trees yield hard wood while conifers yield soft wood

49. **Assertion (A) :** Dry rot is a disease in wood caused by spores germinating in wood cells.

Reason (R): Decomposition and putrefaction of tissues of a standing tree are indications of dry rot.

50. **Assertion (A) :** Knots, one of the common features in wood, are associated with the beginning of branches.

Reason (R) : Knots greatly improve the workability.

51. **Assertion (A) :** Trese which have broad leaves and shed in the autumn are classified as hard woods, while trees having needle like leaves, broadly everygreen are classified as soft woods.

Reason (R) : The term hard woopd and soft wood in relation to a species of tree do not necessarily indicate relative hardness or density.

52. **Assertion (A) :** Within a given species, green timber of large moisture content dries in the same length of time as that of lower moisture content.

Reason (R) : The sapwood which contains most of the moisture, dries more rapidly than the heartwood.

53. **Assertion (A) :** Dimensional changes in wood result due to variation in the moisture content of the wood with atmospheric condition.

Reason (R) : The cell walls in wood are highly hygroscopic and when exposed to moisture, absorb large amounts of water and swell.

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ANSWERS

1.	(d)	15.	(a)	29.	(a)	43.	(c)
2.	(a)	16.	(a)	30.	(c)	44.	(a)
3.	(d)	17.	(b)	31.	(d)	45.	(c)
4.	(c)	18.	(a)	32.	(b)	46.	(b)
5.	(d)	19.	(b)	33.	(b)	47.	(a)
6.	(c)	20.	(a)	34.	(b)	48.	(a)
7.	(a)	21.	(c)	35.	(c)	49.	(c)
8.	(d)	22.	(d)	36.	(c)	50.	(c)
9.	(c)	23.	(a)	37.	(b)	51.	(b)
10.	(b)	24.	(b)	38.	(a)	52.	(d)
11.	(a)	25.	(a)	39.	(c)	53.	(a)
12.	(c)	26.	(b)	40.	(b)		
13.	(b)	27.	(a)	41.	(a)		
14.	(c)	28.	(c)	42.	(d)		

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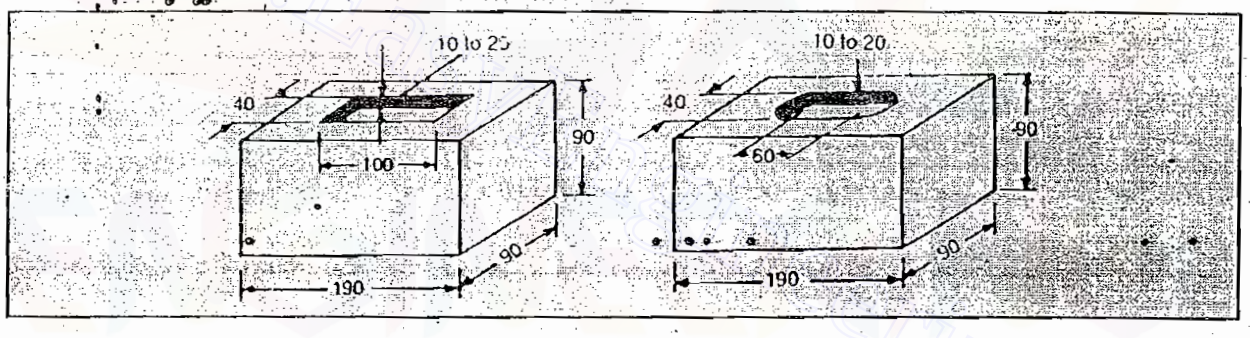
CHAPTER

4

Bricks

INTRODUCTION

- Bricks is one of the oldest building material and it is extensively used at present as a loading material in construction methods because of its durability, strength, reliability, low cost, easy availability, etc.
- Bricks are manufactured by moulding burnt clay or mixture of sand and lime or of portland cement concrete, in rectangular blocks of uniform size and then drying and burning these blocks.
- Bricks are used for building-up exterior and interior walls, partitions, piers, footings and other load bearing structures.



- Size of standard brick (also known as modular brick) is 19 × 9 × 9 cm and 19×9×4, when placed in masonary 19 × 9 × 9 cm brick with mortar it becomes 20 × 10 × 10 cm and weight of such brick is 3 kg.
- An indent called frog, 1-2 cm deep is provided in the brick and size of frog should be 10 × 4 × 1 cm.
- Purpose of providing frog is to form a key for holding the mortar, and therefore the bricks are laid with frogs on top.

Note: In many parts of the country, bricks are still made in non-standardize size which are called as traditional bricks or field bricks. Size of such bricks is = $9^{2} \times 4\frac{1}{2}'' \times 3''$ (23×11.4×7.6 cm).

CLASSIFICATION OF BRICKS

On Field Practice

- Clay bricks are classified as first class, second class, third class and fourth class based on their physical and mechanical properties.

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First Class Bricks

- These bricks are table moulded and they are burnt in kilns.
- These are thoroughly burnt and are of deep red, cherry or copper colour.
- Surface should be smooth and rectangular, with parallel, sharp and straight edges and square corners.
- It should be free from flaws, cracks and stones.
- It should have uniform texture.
- No impression should be left on the brick when a scratch is made by a finger nail.
- Fractured surface of the brick should not show lumps of lime.
- Metallic or ringing sound should come when two bricks are struck against each other.
- Water absorption = 12-15% of its dry weight when immersed in cold water for 24 hours is allowed.
- Crushing strength ≥ 10 N/mm^2.

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

Second Class Bricks

- These bricks have same requirements as first class brick except for the one's listed below.
- These bricks are ground moulded and they are burnt in kilns.
- Small cracks and distortions are permitted.
- Water absorption = 16-20% of its dry weight is allowed.
- Crushing strength ≥ 7.0 N/mm^2.

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

Third Class Bricks

- These bricks are ground-moulded and they are burnt in clamps.
- These bricks are Soft and Reddish yellow coloured.
- Produce a dull sound when struck with each other.
- Water absorption = 25% of dry weight is allowed.
- These have rough surface with irregular and distorted edges.

Uses : For unimportant and temporary structures and at places where rainfall is not heavy.

Fourth Class Bricks

- These bricks are over burnt and badly distorted in shape and size and are brittle in nature.

Uses : Ballast of such brick is used for foundation and floors in lime concrete and road metal, because of fact that own burnt bricks have a compact structure and hence they are sometimes found to be stronger than even first class bricks.

Note : The burnt clay bricks having compressive strength more than 40.0 N/mm^2 are known as heavy duty bricks and are used for heavy duty structures such as bridges, foundations for industrial buildings, multistory buildings, etc. The water absorption of these bricks is limited to 5 per cent.

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On Strength

- Bureau of Indian Standards (BIS) has classified the bricks on the basis of compressive strength and is as given in Table below.

Class	Average compressive strength not less than (N/mm^2)
35	35.0
30	30.0
25	25.0
20	20.0
17.5	17.5
15	15.0
12.5	12.5
10	10.0
7.5	7.5

PROPERTIES OF GOOD BRICK

1. **Size and shape :** Bricks should have uniform size and plane, rectangular surfaces with parallel sides and sharp straight edges.
2. **Colour :** Brick should have a uniform deep red or cherry colour as indicative of uniformity in chemical composition and thoroughness in the burning of the brick.
3. **Texture and compactness :** Surfaces should not be too smooth to cause slipping of mortar. The brick should have precompact and uniform texture. A fractured surface should not show fissures, holes grits or lumps of lime.
4. **Hardness :** Brick should be so hard that when scratched by a finger nail no impression is made.
5. **Soundness :** When two bricks are struck together, a metallic sound should be produced.
6. **Water absorption** $\leq$ 20 per cent of its dry weight when kept immersed in water for 24 hours.
7. **Crushing strength** $\geq$ 10 N/mm^2.
8. **Brick earth** should be free from stones, grits, organic matter etc.

COMPOSITION OF GOOD BRICK EARTH

- Properties of various ingredients is as below.

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

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Silica (50–60%)

- It prevents cracking, shrinking and warping of raw bricks.
- It imparts durability and uniform shape to bricks.
- Excess of silica destroys the cohesion between particles and the bricks become brittle.
- A large percentage of sand or uncombined silica in clay is undesirable. However. It is added to decrease shrinkage in burning and to increase the refractoriness of low alumina clays.

Alumina (20-30%)

- It absorbs water and imparts plasticity to the earth such that it can be moulded.
- It alumina is present in excess , it causes cracks in bricks on drying and becomes too hard when burnt.
- Clays having high alumina are found to be very refractory.

Lime (<10%)

- Prevents the shrinkage on drying.
- It causes silica in clay to melt on burning and hence helps to bind it.
- In carbonated form, lime lowers the fusion point.
- Excess of lime causes the brick to melt and hence brick looses its shape.
- Red bricks are obtained on burning at considerably high temperature (more than 800° C) and buff-burning bricks are formed by increasing the lime content.

Magnesia (<1%)

- A small quantity of magnesia in brick earth imparts yellow tint to the bricks and decreases shrinkage.
- But excess of magnesia leads to the decay of bricks.

Iron Oxide (<7%)

- It gives red colour on burning when excess of oxygen is available and dark brown or even black colour when oxygen available is insufficient, but excess of ferric oxide makes the brick dark blue.
- It improves impermeability and durability.
- It lower the fusion point of the clay, especially if present as ferrous oxide.
- It gives strength and hardness.

HARMFUL INGREDIENTS IN BRICK EARTH

1. Lime

- If lime is present in excess , colour of brick changes from Red to Yellow.
- When lime is present in lumps, it absorbs moisture, swells and causes disintegration of the bricks. Hence lime should be present in finely divided state , and lumps should be removed in the beginning itself.

2. Iron Pyrites

- If iron pyritas are present in brick earth, then bricks tend to oxidise and decompose during burning and may split into pieces.
- Pyrites discolourise the bricks

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3. Pebbles, Gravels, Grits

- It does not allows clay to be mixed uniformly and thoroughly which will result in weak and porous bricks.
- Bricks containing pebbles will not break regularly as desired.

4. Alkalies

- Excess of alkalies causes brick to melt and loose their shape.
- These causes *Efflorescence*- When bricks come in contact with moisture, water is absorbed and the alkalies crystallise. On drying, the moisture evaporates, leaving behind grey or white powder deposits on the brick which spoil the appearance and this phenomenon is called as *efforescence*.

5. Organic Matter

- During burning of bricks, organic matter gets burnt completely, leaving behind pores and hence making bricks porous.
- It also absorbs water and therefore reduces strength of brick.

6. Water

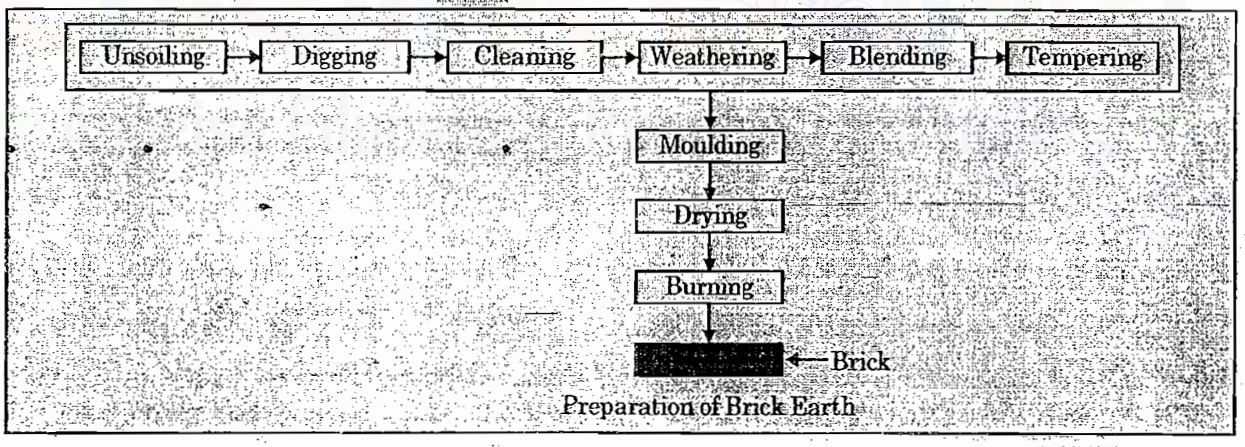
- A large amount of free water causes shrinkage of bricks on drying ,whereas combined water causes shrinkage during burning.

7. Sulphur

- If sulphur is present in brick earth and insufficient time is given (during burning) for oxidation of carbon and sulphur, then sulphur will cause the formation of a spongy, swollen structure in the brick and the brick will be decoloured by white blotches.

MANUFACTURING OF BRICKS

- In the process of manufacturing of bricks, following operations are involved.



1. Preparation of Brick Earth

- Clay for bricks is prepared in the following order:

  (i) Unsoiling (ii) Digging (iii) Cleaning (iv) Weathering
  (v) Blending (vi) Tempering.

  (i) **Unsoiling :** Top layer of soil about 200 mm in depth, is taken out and thrown away as clay in top soil is full of impurities and hence it is rejected for the purpose of preparing bricks.

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(ii) **Digging :** Clay is then dug out from the ground and spread on the levelled ground. Just a little deeper than the general level of ground. The height of heaps of clay is about 600 mm to 1200 mm.

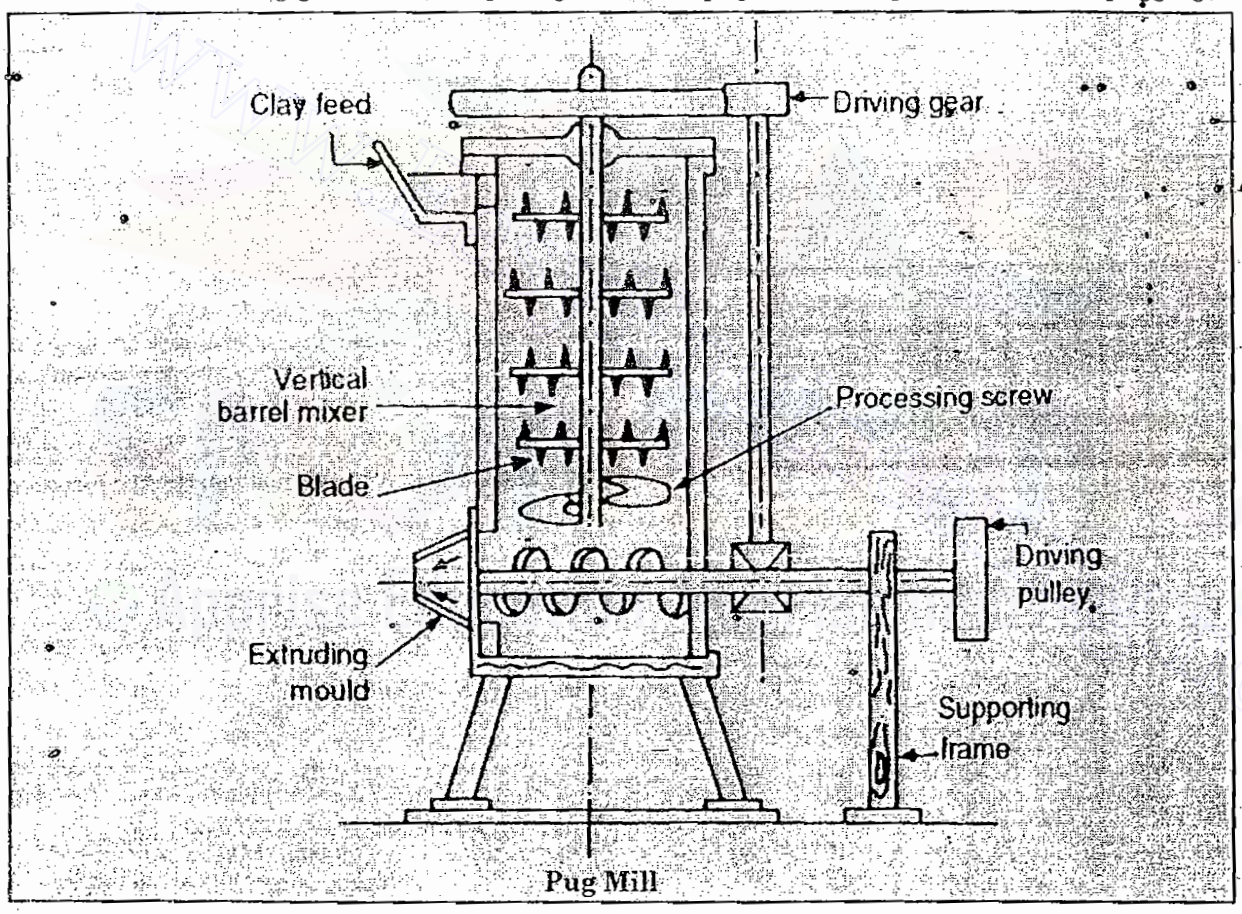
(iii) **Cleaning :** Clay obtained from the process of digging. Should be free from stones, pebbles, vegetable matter, etc. If these particles are in excess, the clay is to be washed and screened. Such a process naturally will prove to be troublesome and expensive. The lumps of clay should be converted into powder form in the earth crushing roller.

(iv) **Weathering :** Clay is then exposed to atmosphere for softening or mellowing, period of exposure varies from few weeks to full season. For a large project, the clay is dug out just before the monsoon and it is allowed to weather throughout the monsoon.

(v) **Blending :** Clay is made loose and any ingredient to be added to it is spread out at its top. It is carried out by taking small portion of clay every time and by turning it up and down in vertical direction.

(vi) **Tempering :** Clay is brought to a proper degree of hardness and it is made fit for the next process of moulding. Water in required quantity is added to clay and the whole mass is kneaded or pressed under the feet of men or cattle.

- For manufacturing good brick, tempering is done in pug mills and operation is called pugging.



Pug Mill

- In pug mill, feeding of clay from top and taking out of pugged clay from bottom are done simultaneously.
- Tempering of clay is done such that brick earth can be rolled without breaking in small threads of 3mm diameter.

2. Moulding

- It is the process of giving required shape to the brick from prepared brick earth.

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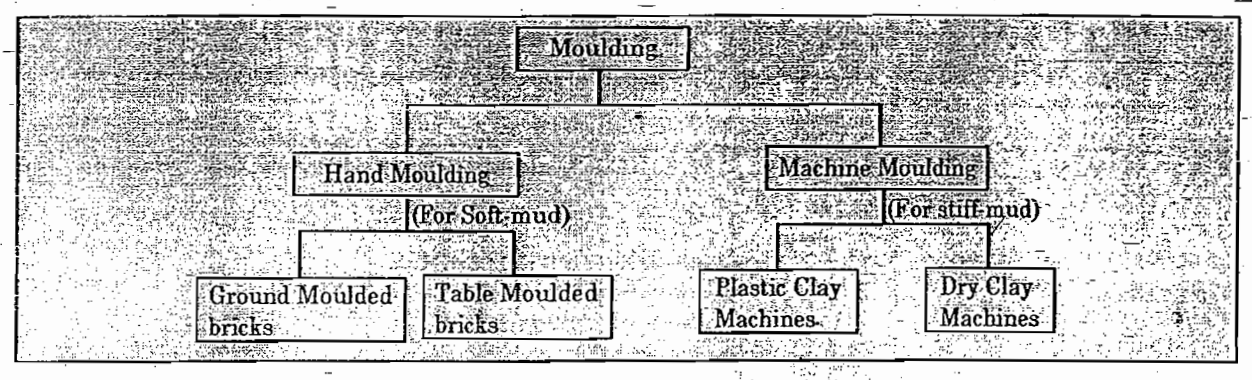
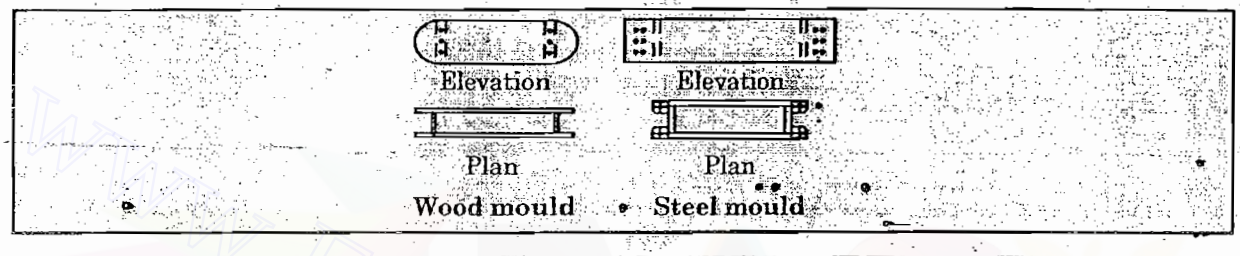


(i) **Hand Moulding**

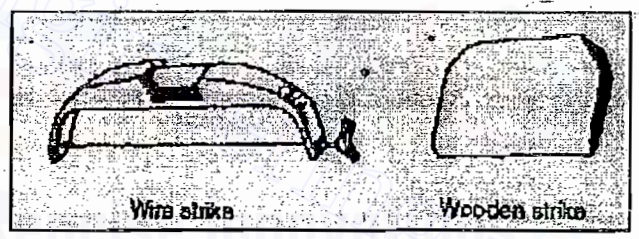
- This method is adopted when manpower is cheap and is easily available for manufacturing of bricks, usually done on small scale.
- Moulds are rectangular boxes of wood or steel, open at top and bottom.



Note: We know that bricks shrinks during drying and burning, therefore moulds are made 8-12% larger in size, that of fully burnt bricks. Exact percentage of increase in dimensions of mould is found by experiments on brick earth at site.

(a) Ground-moulded bricks

- This method is adop]ted when a large and level land is available.
- In this process ground is levelled and sand is sprinkled over it.
- Mould is dipped in water and placed over ground and then clay is pressed in the mould such that it fills all the corners.



- Extra or surplus clay is removed either by a wooden strike or metal strike.
- A strike is a piece of wood or metal with a sharp edge.
- Now mould is lifted and raw brick is left on the ground.
- To prevent the moulded bricks from sticking to the side of the mould, sand is sprinkled on the inner sides of the mould, or the mould may be dipped in water every time before moulding is done.
- If sand is sprinkled then bricks are called as sand-moulded bricks, whereas in case of mould dipped in water bricks are called as slop-moulded bricks.
- Sand moulded bricks are better since they provide sufficient rough surface necessary for achieving a good bond between bricks and mortar.
- Ground-moulded bricks of better quality and with frogs on their surface are made by using a pair of pallet boards and a wooden block.

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(b) Table-Moulded bricks

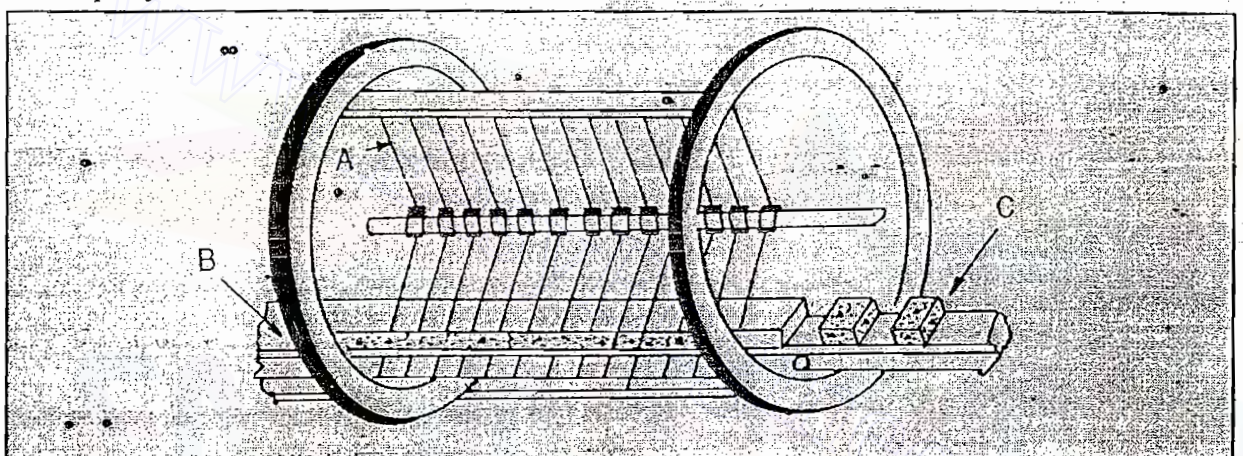
- The process of moulding these bricks is just similar as above. But in this case, the moulder stands near a table of size about 2 × 1m.
- Clay, mould, water pots, stock board, strikes and pallet boards are placed on this table.
- Bricks are moulded on the table and sent for the further process of drying.
- Cost of brick moulding also increase when table moulding is adopted.

(ii) **Machine Moulding**

- Moulding is done with the help of machines when bricks are required in large number of quantity in a short span of time.
- Machine moulding can further be classified into two ways.

(a) Plastic clay machine method.

- In this method bugged stiff clay is forced through a rectangular opening of brick size by means of an auger.
- These bricks comes out of the opening in the form of a bar and further these bricks are cut into strips by wires fixed in frames.



(a) Wire (b) Column of pressed clay passing through die (c) Wire cut brick

Brick cutting wire machine

- As the bricks are cut by wire, they are also known as wire cut bricks.

(b) Dry Clay machine method

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

3. Drying

- If Green bricks (containing 7-30% moisture) are burnt, are likely to be cracked and distorted.
- Therefore moulded bricks are dried to remove moisture for controlling of shrinkage and saving of fuel during burning.
- It is a normal practice to dry moulded bricks to approx moisture content of 5-7%.

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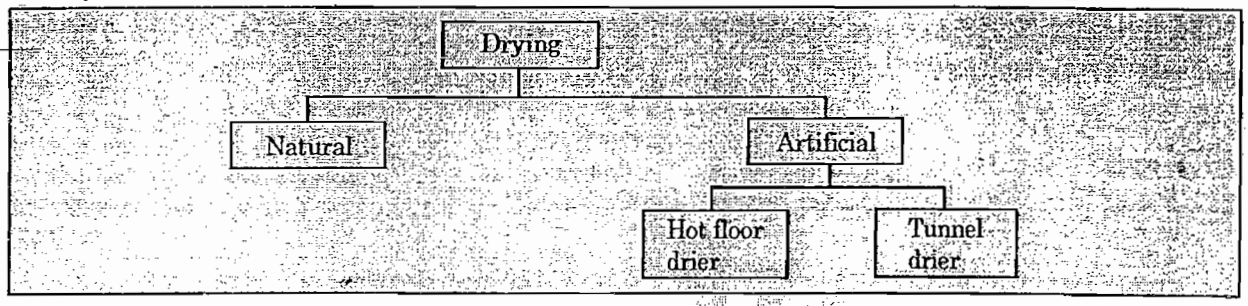
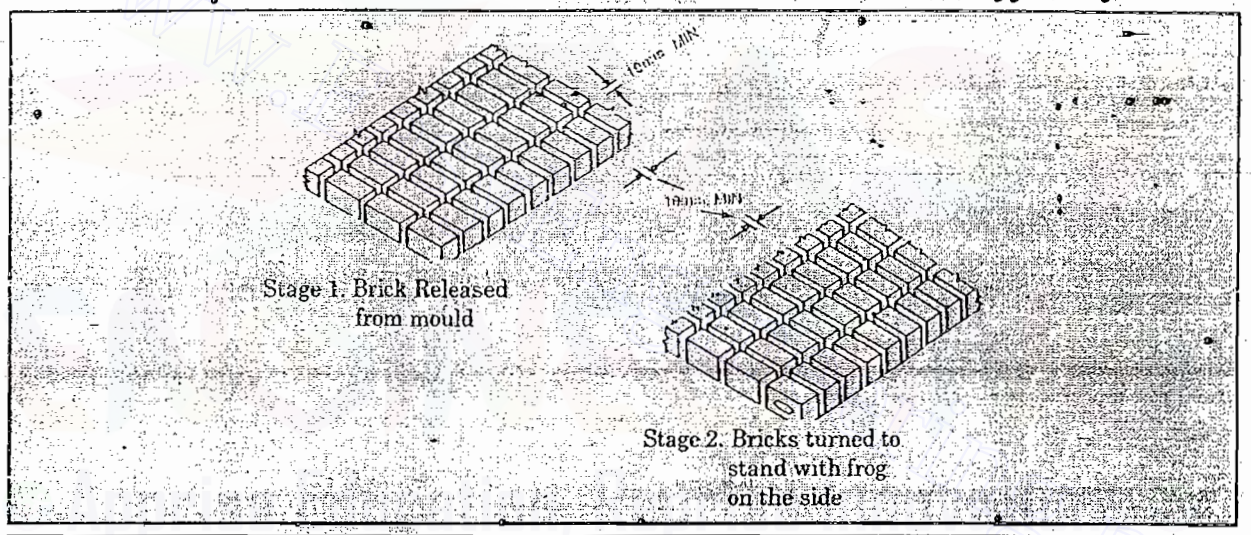
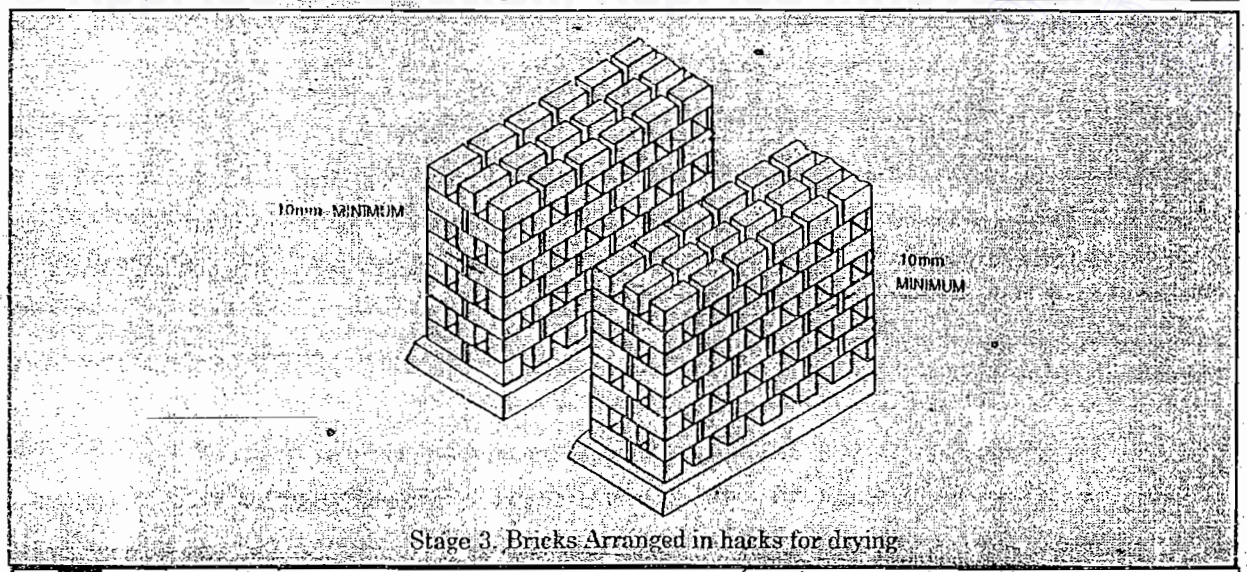
- There are two methods of drying
  (i) Natural drying
  (ii) Artificial drying



(i) Natural drying

- Natural drying is done in several stages as follows.
  1. First bricks are allowed to dry in position as released from the mould.
  2. Then they are turned to stand on edge.
  3. Arranged in rows in rows in hack with spaces of less than 1 cm between the bricks
- Stage 1 and 2 requires 2 to 3 days and stage 3 about one week.





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Institute for Engineers
IES/GATE/PSUs
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Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
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Note : Hack is a rough floor of old bricks or concrete , raised above the ground. If may have a permanent roof and a mouable screen at side.

(ii) Artificial drying

- Bricks are generally dried by natural drying but when bricks are to be rapidly dried on a large scale, artificial drying can be adopted.
- There are two type of dries:
  (a) Hot floor dries.
  (b) Tunnel driers.
- Tunnel drier are more economical than hot floor driers and they may be periodic or continues.
- Temperature maintained by driers is usually less than 120°C and the process of drying of bricks takes about 1 to 3 days.
- The bricks in stacks should be arranged in such a way that sufficient air space is left between them for free circulation of air. It is to be seen that bricks are not directly exposed to the wind or sun for drying suitable screens, if necessary, may be provided to avoid such situations.

4. Burning

- It is very important process in manufacturing of bricks as it provides hardness and strength to the bricks and makes them dense and durable.
- Bricks should be burnt properly. If bricks are overburnt, they will be brittle and hence break easily. If they are underburnt, they will be soft and hence cannot carry loads.
- Burning of bricks can be divided into three stages.

1. **Dehydration (400 – 650°C) :** This is also known as water smoking stage.

(i) The water which has been retained in the pores of the clay after drying is driven off and the clay loses its plasticity,

(ii) Some of the carbonaceous matter is burnt,

(iii) A portion of sulphur is distilled from pyrites.

(iv) Hydrous minerals like ferric hydroxide are dehydrated, and

(v) The carbonate minerals are more or less decarbonated.

2. **Oxidation Period (650 – 900°C):**

(i) Remained of carbon is eliminated and,

(ii) The ferrous iron is oxidized to the ferric form.

(iii) Removal of sulphur is completed only after the carbon has been eliminated.

3. **Vitrification –**

- Convert the mass into glass like substance — the temperature ranges from 900–1100°C for low melting clay and 1000–1250°C for high melting clay.
- A Special care is required in cooling the bricks below the cherry red heat in order to avoid checking and cracking.

Note: Too rapid heating causes cracking or bursting of the bricks. On the other hand, if alkali is contained in the clay or sulphur is present in large amount in the clay, too slow heating of clay produces a scum on the surface of the bricks.

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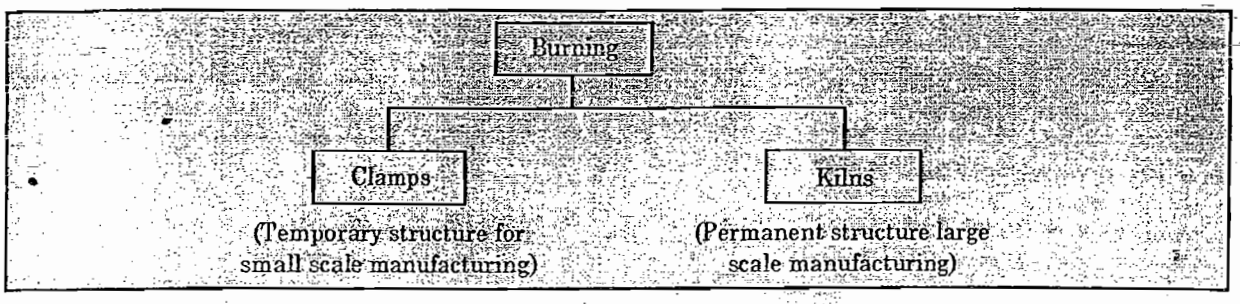
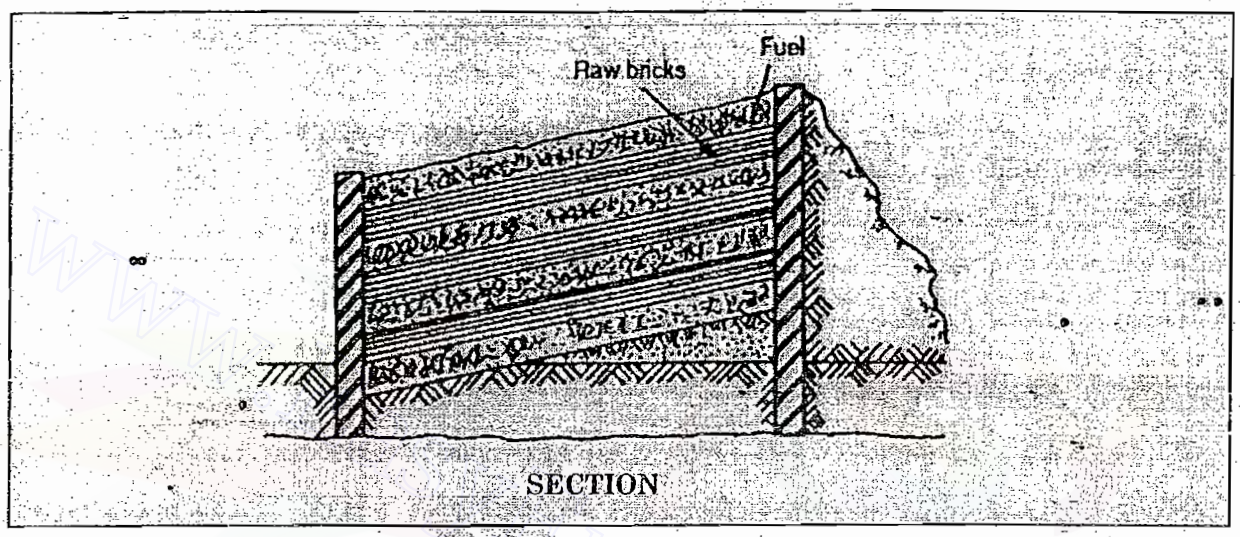
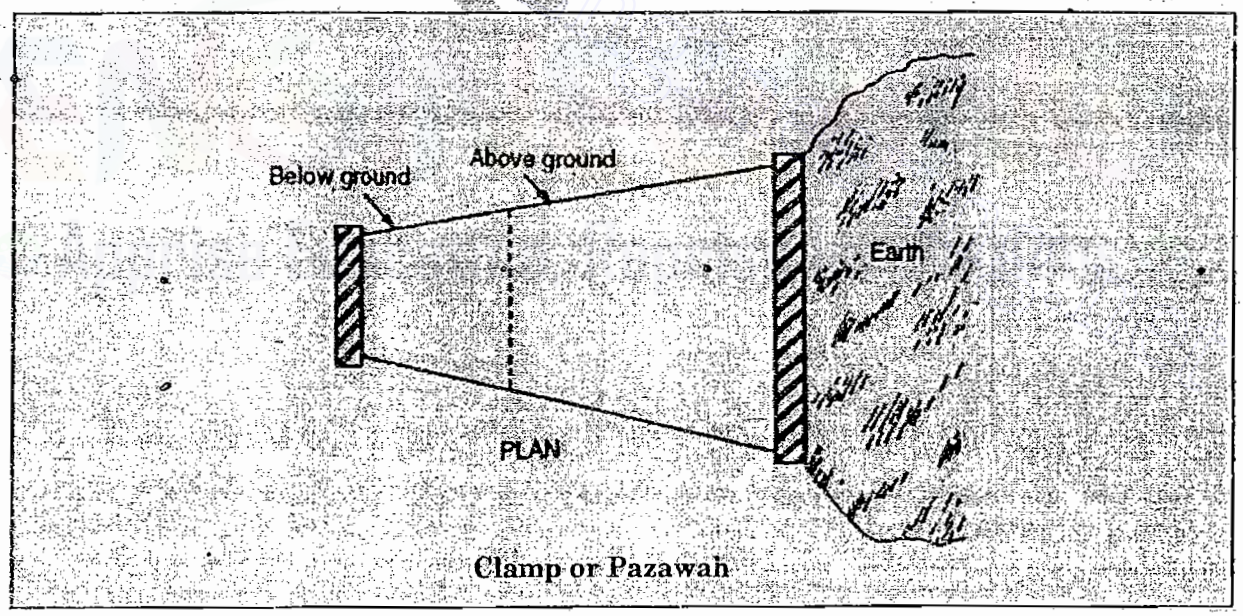
- Burning is either done in clamp on kilns.



Clamp or Pazawah





Clamp or Pazawah

- A piece of land is selected such that its shape in plan is generally trapezoidal land floor of clamp is prepared in such a way that short end is slightly in the excavation and wider end is raised at an angle of about 15° from ground level.

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- Brick wall in mud is constructed on the short end and a layer of fuel is laid on the prepared floor.
- Fuel may consist of grass, cow dung, litter , husks of rice or ground nuts, etc.
- Thickness of this layer is about 700 mm to 800 mm.
- Layer, consisting of 4 or 5 courses of raw bricks, is then put up. The bricks are laid on edges with small spaces between them for the circulation of air.
- Second layer of fuel is then placed and over it, another layer of raw bricks is put up.
- Alternate layers of fuel and raw bricks are formed.
- Thickness of fuel layer gradually decreases as the height of clamp increases.
- Total height of a clamp is about 3m to 4m. When nearly one-third height is reached, the lower portion of the clamp is ignited.
- When clamp is completely constructed, it is plastered with mud on sides and top and filled with earth to prevent the escape of heat.
- Clamp is allowed to burn for a period of about one to two months. It is then allowed to cool for more or less the same period as burning.
- Burnt bricks are then taken out from the clamp.
- **Advantages of clamp burning:**
  1. Burning and cooling of bricks are gradual in clamps. Hence the bricks produced are tough and strong.
  2. Burning of bricks by clamps proves to be cheap and economical. No skilled labour and supervision is required for the construction and working of clamps.
  3. Clamp is not liable to injury from high wind or rain.
  4. There is considerable saving of fuel.
- **Disadvantages of clamp burning:**
  1. Bricks are not of regular shape. This may be due to the settlement of bricks when fuel near bottom is burnt and turned to ashes.
  2. Very slow process.
  3. It is not possible to regulate fire in a clamp once it starts burning and the bricks are liable to uneven burning.
  4. Quality of bricks is not uniform.
  5. Bricks near the bottom are overburnt and those near sides and top are underburnt.

(ii) Kilns

- A kiln is a large oven used to burn bricks.
- Bricks prepared by kilns are better than clamps.

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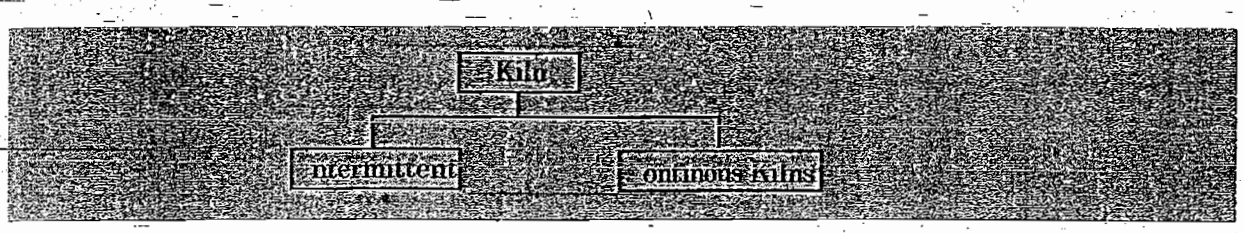
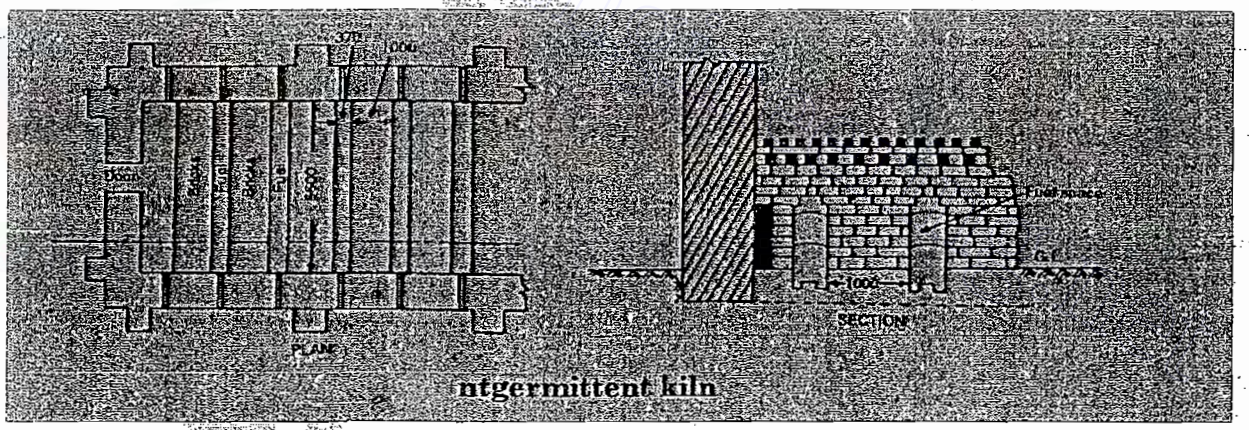


(a) Intermittent Kilns

- Intermittent kilns: These kilns are intermittent in operation which means that they are loaded, fired, cooled and unloaded.
- These be either rectangular or circular in plan.
- They can be overground or underground.
- Intermittent kilns are further divided into two groups.

  (a) Intermittent up-draught kilns

  (b) Intermittent down-draught kilns
- These kilns are in the form of rectangular structure with thick outside walls.
- Wide doors are provided at each end for loading and unloading of kilns.
- Fuel channels or passages are provided to carry flames or hot gasses through the body of kiln
- After loading the kiln, it is fired, loaded and unloaded for next loading.
- Since wall and sides gets cooled during reloading and are to be heated again during next firing , there is a wastage of fuel.



ntgermittent kiln

- Intermittent down- drought kiln gives evenly burnt brick where as in Intermittent -up-draught kiln quality of burnt brick is not uniform, bricks near bottom are overburnt and those near top are underburnt.

(b) Continuous kiln

- These kilns are continuous in operation. i.e. loading, firing, cooling and unloading are carried out simultaneously in these kilns.
- Types of continuous kiln are

  (a) Bull's trench kiln.

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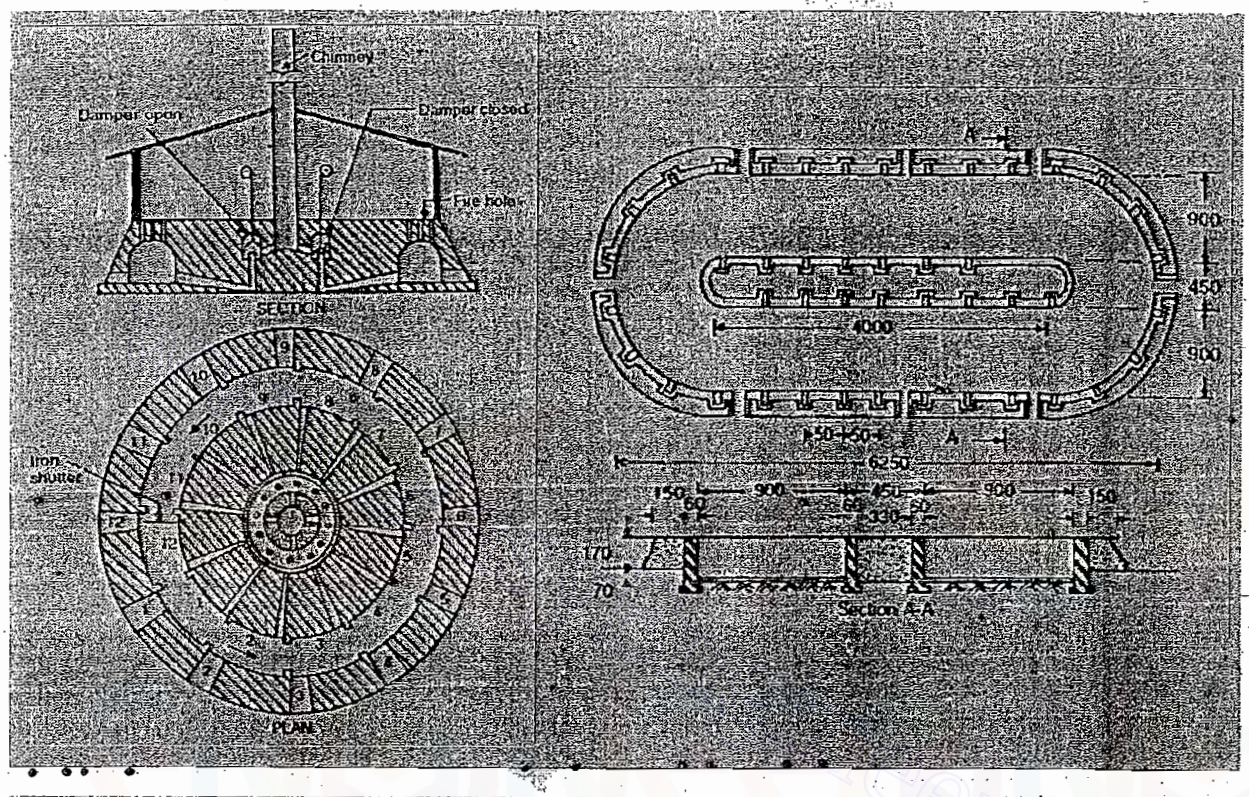
(b) Hoffman's kiln.

(c) Tunnel kiln.

- In a continuous kiln. Bricks are stacked in various chambers wherein the bricks undergo different treatments at the same time.
- When the bricks in one of the chambers is fired, the bricks in the next set of chambers are dried and preheated while bricks in the other set of chambers are loaded and in the last are cooled.



No.	tem	ull's Trench Kiln	offman's Kiln
	Burning capacity	About 3 lakhs in 12 days.	About 40 lakhs in one season.
	ontinuity of orking	It stops functioning during monsoon as it is not provided with a permanent roof.	Functions all the year r und as it s provided with a permanent roof.
	Cost of fuel	High as consumption of fuel is more.	ow as consumption of fuel is less.
	Drying space	It requires more space for drying of bricks.	It requires less space for drying of bricks.
	Initial cost	ow	igh
	ature	t is semi ontinuous in loose ense	t is perfectly Continuous.
	opularity	ore popular because of less initial ost.	ess popular because of high initial ost.
	uality of bricks	ercentage of good quality bricks is mall.	ercentage of good quality bricks is ore.
	uitability	uitable when demand of bricks in onsoon is not substantial.	uitable when demand of bricks is hroughout the year.

I.E.S MASTER
Institute for Engineers
IES/GATE/PSUs
Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
Phone: 011-41013406, 7838813406, 9711853908

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		omparison Between Clamp Burning And Kiln urning	
No	tem	lamp urning	lin urning
	apacity	About 20000 to 100000 bricks can be prepared at a time	Average 25000 bricks can be repared per day
	ost	ow, as grass, cow dung itter, etc ay be used	nerally high as coal dust s to be used
	nitial ost	Very low as no tructures are to be built	More as permanent tructures are to be onstructed
	uality of bricks	he percentage of good quality bricks is small about 60% or so	The percentage of good uality bricks is more bout 90% or so
	egulation of ire	t is not possible to control or egulate fire during the process of burning	The fire is under control throughout the process of burning
	killed supervision	Not necessary through-out the rocess of burning	he continuous skilled upervision is necessary
	tructure	Temporary structure	ermanent tructure
	uitability	Suitable when bricks are to be manufactured on a small scale and when the demand of brick is not continuous	uitable when bricks are to be anufactured on a large cale nd when there is ontinuous emand of bricks
	ime of burning nd cooling	It requires about 2 to 6 onths for burning and cooling of bricks	Actual time for burning of one ham er is about 24 hours and nly about 12 days re required or cooling of bricks
0	astage of heat	There is considerable astage of heat from top and sides and hot fuel gas is not properly utilized	he hot fuel gas is used to dry nd pre eat raw bricks ence he wastage of heat s the least

Tunnel Kiln

- This type of kiln is in the form of tunnel which may be straight, circular or oval in plan.
- It contains a stationary zone of fire.
- Raw bricks are placed on trolleys which are then moved from one end to the other end of tunnel
- Raw bricks get dried and pre-heated as they approach zone of fire. In zone of fire, the bricks are burnt to the required degree and they are then pushed forward for cooling. This kiln proves to be economical when bricks are to be manufactured on a large scale.
- Uniform bricks of better quality are produced.

TESTING OF BRICKS

- A brick is generally subjected to following test to find out its suitability for the construction work.

1. Dimension Test (IS : 1077)

- According to IS : 1077 , standard size of bricks is as follows.

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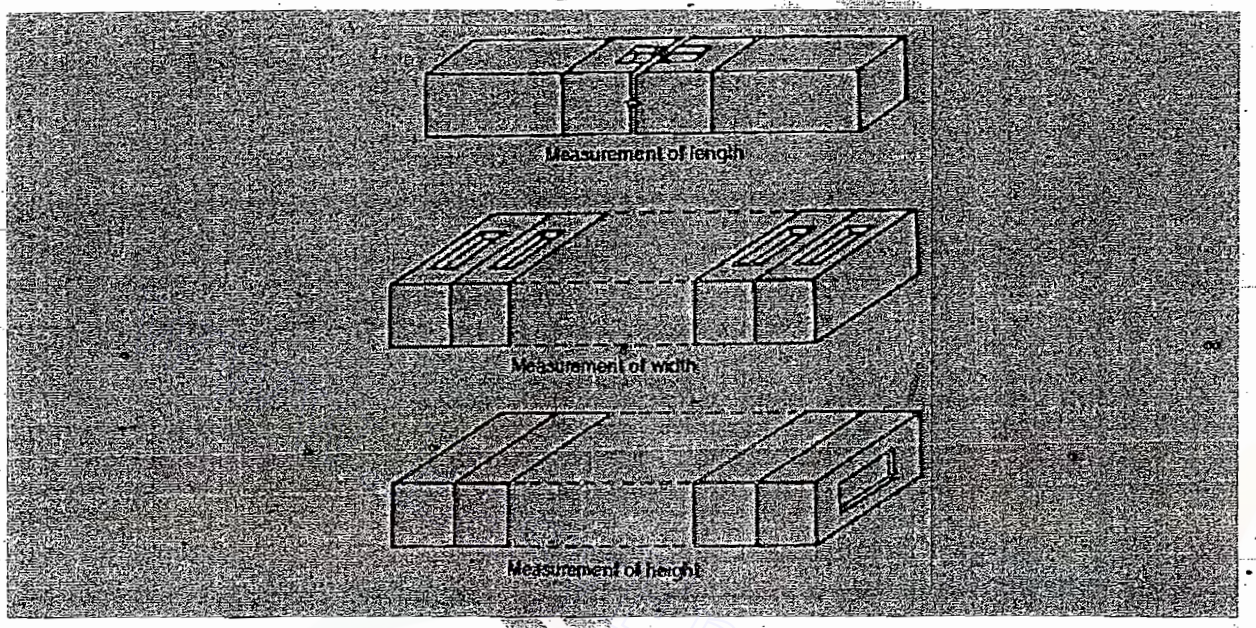
ength	idth	eight
cm)	cm)	cm)
9		
9		

- Dimensions of bricks is tested by stacking 20 bricks as shown in figure below.



	Subclass-A		ubclass-B	
	Dimension (cm)	Tolerance (mm)	imension cm)	olerance mm)
ength	380	± 2	80	± 0
idth	180	±	80	± 5
eight				
i) 9 cm	180	±	80	± 5
ii) 4cm	80	±	0	±

2. Water Absorption Test (IS : 3495-Part III)

- Water absorption of bricks depends on their porosity which is due to voids of various size present in the bricks.
- Almost all bricks absorbs water by capillary action.
- But porosity and water absorption does not give proper indication as to whether brick work can keep away the rain water and protect the interior from dampness travelling from outside.
- Permeability measures the travel of moisture through a brick.
- Percentage of water absorption gives indication of compactness which is obtained from burning. (Vitrification in real sense).

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(i) 24 Hour Immersion Cold water Test

- Dry bricks are kept in oven $(105-115^{\circ}C)$ till it attains constant mass.
- After cooling the bricks to room temperature its weight is recorded as W_1.
- Now bricks are immersed in water at a temperature of $27^{\circ} \pm 2^{\circ}C$ for 24 hours.
- Bricks are then taken out of water and wiped with a damp cloth and weighted as W_2 after 3min.

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

- Average water absorption shall not be more than 20% by weight upto class 125 and 15% by weight for higher classes.

Note: For water absorption less than 5% , danger of frost action is negligible.

(ii) Five Hours Boiling Water Test

- Weight of the oven dried bricks (W_1) is recorded as above. Then the specimen is immersed in the water and boiled for five hours, followed by cooling down to 27° ± 2°C by natural loss of heat within 16–19 hours. Then bricks is taken out of water and wiped with a damp cloth and the weight is recorded as W_3.

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

3. Compressive Strength test (IS : 3495-Part I)

- Bricks are often subjected to large compressive stresses.
- Compressive stresses of bricks provides a basics of comparison of quality of bricks, but it is of little value in determining the strength of wall, as strength of wall mainly depends on the strength of mortar.
- Asper IS-1077-1976 , Common building brick shall have minimum strength of 35 kg f/cm^2 (3.5 N/mm^2)

Average Compressive Strength of Common Burnt Clay Bricks

Class designation	Average not less than kgf/cm^2(N/mm^2)
350	350 (35)
300	300 (30)
250	250 (25)
200	200 (20)
175	175 (17.5)
150	150 (15)
125	125 (12.5
100	100 (10)
75	75 (7.5)
50	50 (5)
35	35 (3.5)

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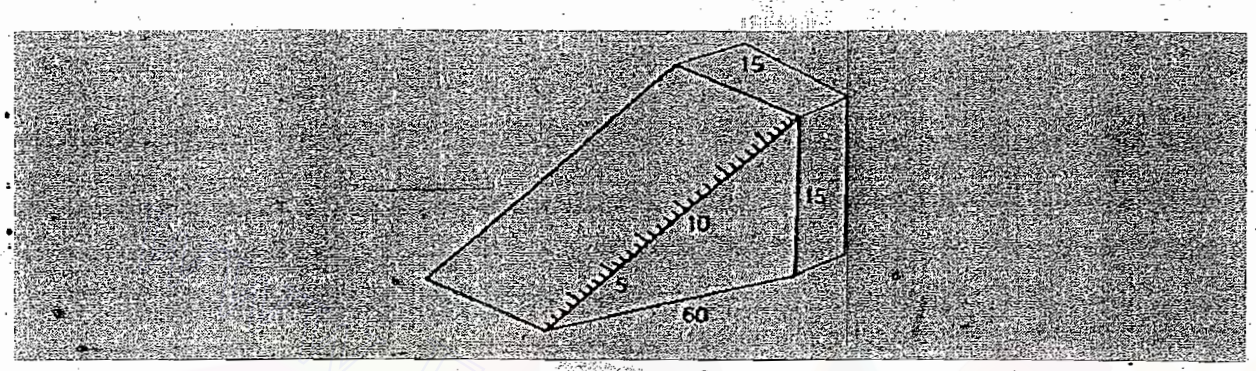
- Bricks is immersed in water for 24 hours.
- Frog of brick is filled flush with 1 : 3 mortar and the brick is stored under damp gunny bags (jute bags) for 24 hours followed by immersion in clean water for 3 days.
- Bricks is then placed in compression testing machines and load is applied axially at a uniform rate of 14N/mm^2 and maximum load at which brick fails is recorded for calculation of compressive strength

$$\text{Compressive strength} = \frac{\text{Max. Load at failure}}{\text{Loaded area of brick}}$$

4. Warpage Test (IS : 3495-Part IV)



- Warpage of the brick is measured with the help of a flat steel or glass surface
- and measuring ruler graduated in 0.5 mm divisions or wedge of steel 60 × 15 × 15 mm

(i) Concave Warpage

- Flat surface of the brick is placed along the surface to be measured selecting the location that gives the greatest deviation from straightness.
- Greatest distance of brick surface from the edge of straightness is measured by a steel ruler or wedge.

(ii) Convex Warpage

- Brick is place on the plane surface with the convex surface in contact with the flat surface and the distances of four corners of brick are measured from the flat surface.
- Largest distance is reported as warpage.
- Higher of the distance measured in concave and convexwarpage tests is taken as warpage.

5. Efflorescence Test (IS : 3495-Part III)

- Ends of the brick are kept in a 150 mm diameter porcelain or glass dish containing 25 mm depth of water at room temperature (20°–30°C) till the entire water is absorbed or evaporated
- Water is again filled to 25 mm depth in the dish and allowed to be absorbed by the brick or evaporated
- Bricks are examined after second evaporation and area of white patches is measured on the brick.
- Presence of efflorescence is classified as

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

- The specifications limit the efflorescence to be not more than moderate (10–50%) up to class 12.5 and not more than slight (<10%) for higher classes.

DEFECTS OF BRICKS

1. Over-Burning of Bricks

- If the bricks are overburnt, a soft molten mass is produced and the bricks loose their shape. Such bricks are not used for construction works.

2. Under-Burning of Bricks

- When bricks are not burnt properly, the clay is not softened because of insufficient heat and the pores are not closed.
- This results in higher degree of water absorption and less compressive strength
- Such bricks are not recommended for construction works.

3. Bloating

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

4. Black Core

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

5. Efforescence

- This is caused because of alkalies present in bricks.
- When bricks come in contact with moisture, water is absorbed and the alkalies crystalise.
- After drying grey or white powder patches appear on the brick surface. This can be reduced by selecting proper clay materials for brick manufacturing, preventing moisture to come in contact with the masonry, by providing waterproof coping and by using water repellent materials in mortar and by providing damp proof course.

6. Chuffs

- Deformation of the shape of bricks caused by the rain water falling on hot bricks is known as chuffs.

7. Checks or Cracks

- This is because of lumps of lime or excess of water.

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In case of lime, when bricks come in contact with water, the absorbed water reacts with lime nodules causing expansion and a consequent disintegration of bricks, whereas shrinkage and burning cracks result when excess of water is added during brick manufacturing.

8. Spots

If sulphide, is present in the brick clay, it cause dark surface spots on the brick surfaces. Such bricks are not only harmful but also unsuitable for exposed masonry work.

9. Blisters

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

10. Laminations

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

SPECIAL BRICKS

1. Heavy Duty Burnt Clay Bricks (IS : 2180)

- These bricks are similar to burnt clay bricks and of same size but with high compressive strength.
- These are free from cracks, flaws and nodules of free lime.
- These are used in masorary in heavy engineering works such bridges , industrial foundation and multi-storeyed buildings.
- Classification: Class 400 : compressive strength not less than 40.0 N/mm^2.
  Class450 : compressive strength not less than 45.0 N/mm^2.
- These are further subdivided as subclasses A and B based on tolerance.

Tolerance

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

Water absorption: < 10 per cent after 24 hours immersion in water.

Efforescence: should be nill.

Bulk density: < 2500 kg/m^3.

2. Bunrt Clay Perforated Bricks (IS : 2222)

- These bricks have cylindrical holes throughout their thickness, have high compressive strength and less water absorption. These bricks are light in weight, require less quantity of clay, drying and burning of these bricks is easy and economical.
- Direction of perforations can be vertical or horizontal.
- Area of perforations should not exceed 30 to 45% of the area of face
- In case of rectangular perforations, larger dimensions should be parallel to longer side of the brick.

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- These are used in building walls and partitions

Dimensions

(i) $19 \times 9 \times 9cm$ (ii) $29 \times 9 \times 9cm$

Tolerance

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

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

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

Compressive strength < 7.0 N/mm^2.

Water absorption < 15 percent

Efflorescence should not be more than slight.

Warpage < 3 percent.

3. Burnt Clay Facing Bricks (IS : 2691)

- These bricks are used in the exposed face of masorary without any further surface protection.
- In corrosive atmosphere and high rise. Buildings , use of facing bricks is economical
- These are classified as

(a) Class I – Compressive strength > 100kgF/cm^2

(b) ClassII – Compressive strength > 75kgF/cm^2

- Water absorption < 15% , for 24 hours immersion
- Efforescence – Nil , for both classes.
- Warpage < 2.5 mm, for both classes.
- These bricks should be free from cracks, flaws and nodules of free lime.
- These bricks are available in size.

(a) $19 \times 9 \times 9cm$

(b) $19 \times 9 \times 4cm$

4. Burnt Clay paving Bricks (IS : 3583)

- In these bricks iron content is more than that in the ordinary clay bricks.
- Excessive iron causes vitrification of bricks while burning at a low temperature, give natural glaze to the brick, and making it more resistant to abrasion.
- Paving bricks are manufactured from surface clays, impure fire-clays or shale. Shales are the best raw material for paving bricks.
- These are generally burned in continuous kiln for seven to ten days.

Dimension:

(i) $19.5 \times 9.5 \times 9cm$

(ii) $19.5 \times 9.5 \times 4cm$

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Tolerances

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

5. Burnt Clay Soiling Bricks (IS : 5779)

- These are used for soling of roads.
- Dimensions
  - (i) $19 \times 9 \times 9cm$
  - (ii) $19 \times 9 \times 4cm$
- Tolerances: Overall dimensions of 20 bricks (selected) should be within following limits.

Length $370 - 388cm(380 \pm 8cm)$

Width $176 - 184cm(18 \pm 4cm)$

Height $For \begin{cases} 9cm \text{ bricks} & 176 - 184cm \\ 4cm \text{ bricks} & 76 - 84cm \end{cases}$

Compressive strength ≥ 5.0 N/mm^2.

Water Absorption < 20 percent by weight after immersion for about 24 hours in cold water.

Efforescence : < slight.

6. Burnt Clay Hollow Blocks (IS : 3952)

- These are blocks, also known as cellular or cavity blocks, are manufactured from a thoroughly ground, lump free, well mixed clay mass of medium plasticity to allow moulding
- Process of manufacture is similar to that of stiff-mud bricks
- Used to reduce the dead weight of the masonry and for exterior as well as partition walls
- They reduce the transmission of heat, sound and dampness.

Types

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

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

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

Dimensions

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

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Institute for Engineers
IES/GATE/PSUs
Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
Phone: 011-41013406, 7838813406, 9711853908

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Tolerances

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

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

Water absorption < 20 percent.

7. Sand Lime Bricks (IS : 4139)

- These bricks also called calcium silicate bricks,
- It consist essentially of an intimate and uniform mixture of siliceous sand or crushed siliceous rock and lime combined by the action of saturated steam under pressure.
- By heating the mixture under pressure, hydrated silicates and aluminates are formed which bind the sand grains together.
- Used for masonry construction just like burnt clay bricks.
- Dimensions

  (a) $19 \times 9 \times 9cm$ (b) $19 \times 9 \times 4cm$
- Tolerance : Length ± 3mm
  Width ± 2mm
  Height ± 2mm
- These bricks are classified depending on their average compressive strength.

Classification of Sand lime Bricks

Class	Average compressive strength $kgf/cm^2 (N/mm^2)$ Not less than	$kgf/cm^2 (N/mm^2)$ less than
75	75 (7.5)	100 (10)
100	100 (10)	150 (15)
150	150 (15)	200 (20)
200	200 (20)	200 (20)

- Average drying shrinkage of these bricks shall be less shan as per table below.

Class	Drying shrinkage (percent of the wet length)
75	0.025
100	0.025
150	0.035
200	—

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8. Sewer Bricks (IS : 44885)

- These bricks are manufactured from surface clay, fine clay, or shale or a combination of these materials.
- These bricks are used for lining of walls, roofs and floors of severs used for ordinary sanitary (domestic) sewage.
- Generally common building bricks are used for construction of sewers , which is not satisfactorily. It is observed that sewer bricks are also not suitable for sewer dealing with industrial effluent for which IS (4860) code suggests use of Acid-resistant bricks.
- Dimensions

  (a) 19×9×9cm

  (b) 19×9×4cm

  For sewer of special shapes , bricks may have to be suitably tapered to conform the requirement
- Tolerance

Dimension (cm)	Tolerances (mm)
19	± 5
9	± 2
4	±1.5

- Warpage – 2.5 mm
- Average compressive strength >175kgF/cm^2
- Water absorbtion <12%, 20 hrs cold water immersion
- Efflorescence – less than slight

9. Acid Resistant Bricks (IS : 4860)

- Used for masonry constructions, buildings subjected to acid attacks, lining of chambers and towers in chemical plants , lining of sewers carrying industrial effluents, etc. to prevent deterioration of surface by acid except hydrofluoric acid and perchloric acid and other chemicals.
- These bricks are made of raw materials, such as clay or shale of suitable composition with low lime and iron content, feldspar, flints or sand and vitrified at high temperatures in a ceramic kiln.
- Dimension for acid resistant bricks are $230 \times 114 \times 64 mm$.
- Permissible tolerance values on the dimensions are as follows:

Dimensions (cm)	Tolerances (mm)
230	±3.5
114	±2.0
64	±1.0

- Acid resistant bricks are manufactured in two classes satisfying the requirements given in

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Performance Requirements of Acid Resistant Bricks

Characteristic	Requirement for	
	Class I bricks	Class II bricks
Water absorption percent (max.)	2	4
Flexural strength kg/cm^2 (min)	100	70
Compressive strength kg/cm^2 (min)	700	500
Resistance to acid	Loss of weight should not exceed 1.5%	Loss of weight should not exceed 4%

- Class I bricks are recommended for severe type of corrosive environments as obtained in storage tanks, etc. and also in heavy duty floors subject to frequent contact with corrosives.
- Class II bricks are recommended for floors and working areas which are subject to occasional spillage of acids, flumes and contact with dry chemicals as in fertilizer silos. These may also be used for skirting and lining of silos.

10. Refractory Bricks/Fire clay Bricks

- Refractory bricks are defined as non metallic material suitable for construction or lining of fornaces operated at high temperatures.
- These bricks are made form fire clay or Refractory clay.

Fire/Refractory Clay

- Fire-clay is a term, loosely applied, to include those sedimentary or residual clays which vitrify at a very high temperature and which, when so burnt, possess great resistance to heat.
- These are pure hydrated silicates of alumina and contain a large proportion of silica 55–75%, alumina 20–35%, iron oxide 2–5% with about 1 per cent of lime, magnesia and alkalis.
- If greater is the percentage of alumina, more refractory the clay is found to be.
- Fire clays are capable of resisting very high temperatures up to 1700°C without melting or softening and resist spelling.
- Presence of a small percentage of lime and magnesia and alkalis help to melt the clay particles more firmly, whereas a large percentage of lime and magnesia tend to melt the clay at low temperatures.
- Iron oxide or other alkalis reduce refractory qualities of fire clay.
- The process of manufacturing is as of an ordinary brick, burnt at very high temperatures in special kilns (Hoffman's kiln).
- Fire clay mortar is used to clay rerfractory bricks.

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Properties

1. The colour is whitish yellow or light brown.
2. The water absorption of fire-clay bricks varies from 4–10%
3. The minimum average compressive strength of the bricks should be 3.5 N/mm2.

- These bricks are of following types
  (i) Acid bricks.
  (ii) Basic bricks.
  (iii) Neutral bricks.

(i) Acid Bricks

Acid bricks are further classified as

(a) Fire bricks

(b) Silica bricks

(a) Fire bricks :

- These are made from fire clays which are generally mixed with a small percentage of sand to reduce shrinkage during burning.
- These bricks should be able to stand a temperature of 1700°C and should withstand a load of 2kg/cm^2 at a temperature of 1350°C.

(b) Silica bricks :

- These are made from quartzite and sand-stone or silica sand which contains more than 95% of silica. but, the ground siliceous rock or sand are not sufficiently plastic when tempered with water and are mixed either with 2% of high calcium lime to act as binding material or a very small percentage of fire clay is added.
- Compressive strength of silica bricks is often more than 150 kg/cm^2 and the softening temperature ranges between 1300°C and 1800°C.
- These bricks have a large coefficient of expansion and are laid with a wide joint.

Note: Both fire bricks and silica bricks are used in steel industry and coke oven and cannot be used in intermittently operated furnaces.

(ii) Basic Bricks

These are manufactured from magnesite, dolomite, bauxite, etc. Common types are

(a) Magnesite bricks

(b) Dolomite bricks

(c) Bauxite bricks

(a) Magnesite bricks :

- As per IS : 1749-1961, the chemical composition for these bricks is as follows:
  Magnesia (MgO) (min.85%); calcium oxide (CaO) (max 25%); and silica (SiO_2) (max 5.5%).
- Magnesite bricks are used for lining basic Bessemer converters, basic open hearth furnaces, blast furnaces, copper furnaces and in various metallurgical processes.

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(b) Dolomite bricks :

- These are not as satisfactory as magnesite bricks.
- These are made of calcined dolomite, the carbonate of magnesia and lime.

(c) Bauxite bricks :

- Bauxite which consists of 50% or more of alumina and iron oxide and silica as impurities is calcined and crushed to a fine powder. It is then mixed with 15 to 30% of fire clay and with water and then moulded.
- Properly burnt bauxite bricks are highly refractory they have not come into general use because of high shrinkage at high temperature.

(iii) Neutral Bricks

- In furnaces and in certain flues, where the reaction of the surrounding medium may be either acidic or basic refractory bricks, which are netural in reaction are used.
- The various types of neutral bricks are
  (a) Chrome bricks
  (b) Chrome-magnesite bricks
  (c) Spinel
  (d) Forsterite bricks.

(a) *Chrome bricks :*

These contain 30 to 40% of chrome oxide, the remainder being mainly oxide of magnesium, aluminium and silicon. They posses great resistance to the corrosive action of slags and gases. They are less refractory and weaker than magnesia bricks.

(b) *Chrome-magnesite bricks :*

These are made from a mixture of chrome ore and magnesite with a predominating percentage of chrome ore.

Chrome-magnesite bricks posses good mechanical properties.

(c) *Spinel :*

It is a special refractory produced in an electric furnace consisting of magnesia and alumina.

(d) *Forsterite bricks :*

These are made from the mineral forsterite ($2MgO.SiO_2$).They have less shrinkage and possess good mechanical properties at high temperature.

Note: Refractory bricks are always set in a mortar of fire clay and not in lime or cement mortar.

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CONVENTIONAL QUESTIONS

1. Describe the various tests specified for judging the qualities of a given sample of bricks. (1987)
2. Enumerate the requirements for good brick. (1989)
3. Describe the tests for the acceptance of bricks for building construction. (1991)
4. How are bricks classified as per I.S. code? What are the properties assciated with this classification? (1998)
5. Write short notes on the following bricks :
   (i) Table moulded
   (ii) Refractory
   (iii) Pressed
   (iv) Machine moulded (2001)
6. Explain absorption & saturation factors with regard to bricks. (2002)
7. List four important tests conducted on the bricks. Describe briefly the method used to determine compressive strength of bricks. (2003)
8. Describe in brief the classification of ordinary bricks according to their qualities into four categories. (2004)
9. What are the properties governing the quality of bricks? Discuss the importance of water absorption and strength under compression. (2005)
10. Explain various defects in bricks. (2006)
11. Write about the following tests on clay bricks and mention the desired test limits as per Indian Standards :
    (i) Water absorption
    (ii) Cushing strength
    (iii) Hardness
    (iv) Soundness
    (v) Presence of soluble salts (2007)
12. What are the principal constituents of brick earth and how do they influence the quality of brick? (2008)

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OBJECTIVE QUESTIONS

1. A good brick should not absorb water by weight more than
   (a) 10% (b) 20%
   (c) 25% (d) 30%

2. Consider the following statements:
   1. About 25% of alumina in brick earth imparts the plasticity necessary for moulding bricks into required shape.
   2. Iron pyrite present in brick earth preserves the form of the bricks at high temperatures.
   3. Presence of weeds in brick earth makes the bricks unsound.

   Which of these statements are correct ?
   (a) 1 and 2 (b) 1 and 3
   (c) 2 and 3 (d) 1, 2 and 3

3. The most important purpose of frog in a brick is to
   (a) emboss manufacturer's name
   (b) reduce the weight of brick
   (c) form keyed joint between brick and mortar
   (d) improve insulation by providing 'hollows'

4. Bricks are burnt at a temperature range of
   (a) 500° to 700°C (b) 700° to 900°C
   (c) 900° to 1200°C (d) 1200° to 1500°C

5. Which one of the following procedure is applied to determine the soundness of bricks?
   (a) Immersing the brick under water for 16 hours and determining the quantity of water absorbed by the brick.
   (b) Immersing the brick under water for 24 hours and determining its expansion using Le Chatelier apparatus.
   (c) Taking two bricks, hitting one against the other and observing whether they break or not and the type of sound produced while hitting.
   (d) Scratching the brick by finger nail and noting whether any impression is made or not.

6. The minimum compressive strength of first class bricks should be
   (a) 5 N/mm^2 (b) 7.5 N/mm^2
   (c) 9 N/mm^2 (d) 10 N/mm^2

I.E.S MASTER
Institute for Engineers
IES/GATE/PSUs
Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
Phone: 011-41013406, 7838813406, 9711853908

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7. Match **List-I** (Test) with **List-II** (Procedure) and select the correct answer using the codes given below the lists:

List-I

A. Absorption

B. Hardness

C. Soundness

D. Structure

List-II

1. A brick is to be broken for the test
2. Two bricks are taken and they can be struck with each other without breaking
3. A scratch is easily made on brick surface with the help of a finger nail
4. Difference in weight between the brick immersed in water for 16 hours and its dry weight.

Codes :

	A	B	C	D
(a)	1	3	2	4
(b)	4	3	2	1
(c)	4	2	3	1
(d)	1	2	3	4

8. Refractory bricks resist

(a) high temperature (b) chemical action

(c) dampness (d) all of the above

9. When a first class brick is immersed in cold water for 24 hours, it should not absorb water by weight more than

(a) 15% (b) 20%

(c) 25% (d) 30%

10. Which one of the following is the nominal size of standard modular brick?

(a) 25 cm × 13 cm × 8 cm (b) 25 cm × 10 cm × 8 cm

(c) 20 cm × 10 cm × 10 cm (d) 20 cm × 15 cm × 10 cm

11. Consider the following statements:

1. Soil containing more than 30% of calcium hydroxide is used for manufacture of sand lime brick.
2. Carbon brick is made from crushed coke bonded with tar.

Which of these statements is/are correct?

(a) 1 only (b) 2 only

(c) Both 1 and 2 (d) Neither 1 nor 2

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12. The average compressive strength of a burnt clay brick is less than 12.5 N/mm^2. The allowable rating of efflorescence is

(a) moderate (b) serious

(c) heavy (d) zero

13. Consider the following statements:

1. Bricks lose their strength by 25% when soaked in water
2. Minimum crushing strength of brick in buildings should be 35 kg/cm^2
3. The size of modular type bricks is 20 cm × 10 cm × 10 cm including mortar thickness.

Which of these statements are correct?

(a) 1, 2 and 3 (b) 1 and 2 only

(c) 1 and 3 only (d) 2 and 3 only

14. **Assertion (A)** : More uniformly burnt bricks are obtained from a downward draught kiln.

Reason (R) : A higher percentage of tricalcium silicate in cement results in slow hardening and less heat of hydration and greater resistance to chemical attack.

ANSWERS

1.	(b)	5.	(c)	9.	(b)	13.	(d)
2.	(b)	6.	(d)	10.	(c)	14.	(b)
3.	(c)	7.	(b)	11.	(b)		
4.	(c)	8.	(d)	12.	(a)		

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CHAPTER

5

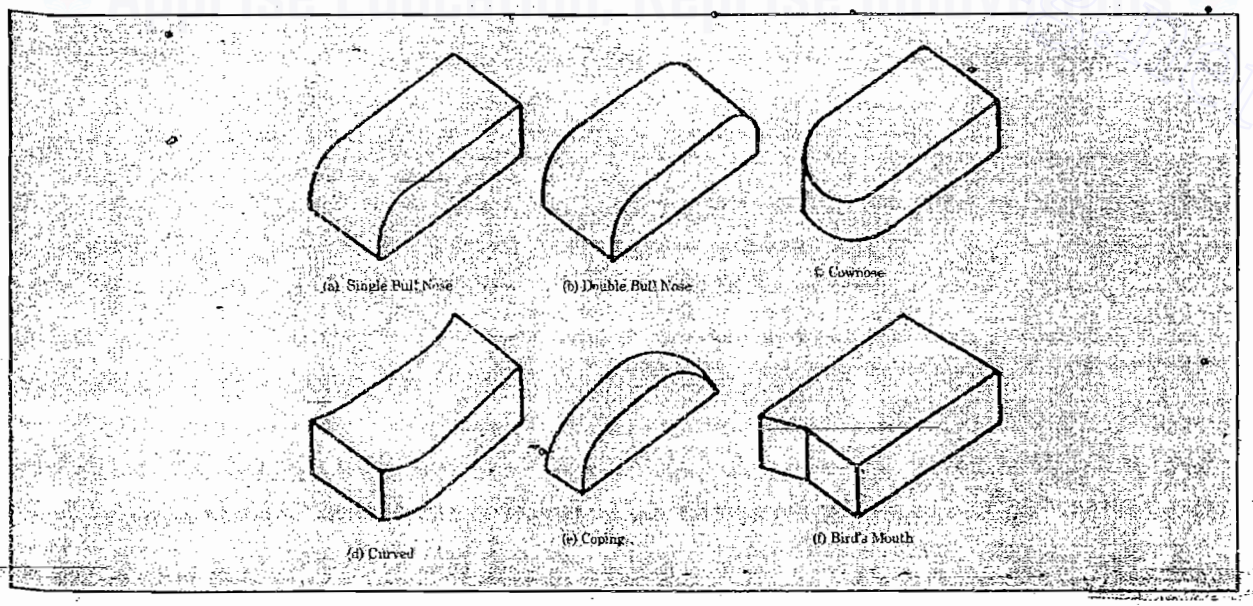
Brick Masonary

INTRODUCTION

- Brick masonary is made up of bricks bonded together with mortar. Therefore two essential requirements of bricks masonary is :
  1. Bricks
  2. Mortar
- We will discuss both bricks and mortar requirements for bricks in this chapter.

BRICKS

- Bricks used in masonary can be of two types.
  (i) Traditional/country bricks (23 × 11.4 × 7.5 cm)
  (ii) Modular bricks (19 × 9 × 9)
- Some times bricks are also manufactured into special shapes and sizes for architectural purpose *e.g.* copings, cornices, string courses, slopping walls etc.
- Few commonly used specially shaped bricks are as below.



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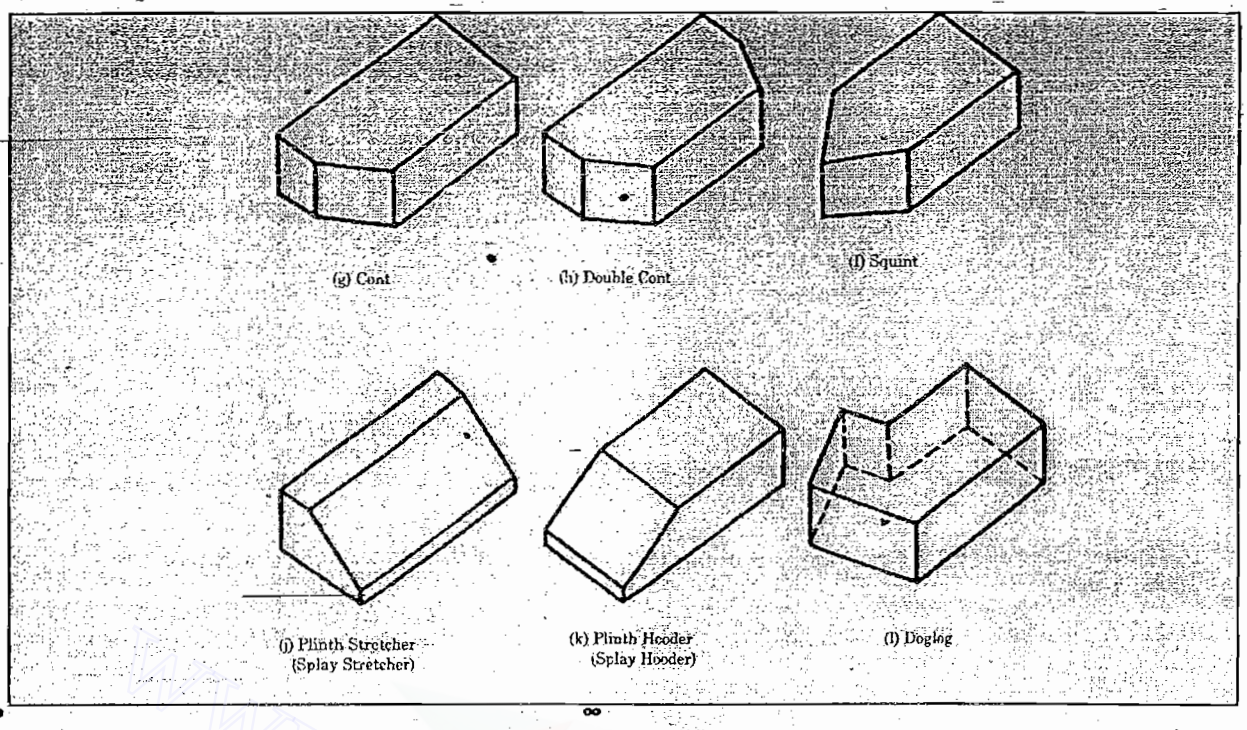

MORTAR

- Mortar is defined as a mixture containing a binding agent (cement) water and aggregate (sand), and acquiring stone-like properties as a result of hardening.
- In composition and properties, building mortars are similar to concrete, but these do not contain coarse aggregate.
- Mortars are used for filling joints as a binder in stone and brick masonry, for preparation of decorative and protective plasters and the production of small size building elements (blocks, bricks, tiles etc.).

CLASSIFICATION OF MORTARS

- Mortars are classified on the basis of the following :
  - (i) Bulk density
  - (ii) Kind of binding material
  - (iii) Nature of application
  - (iv) Special mortars.

(i) Bulk Density : According to bulk density of mortar in dry state, there are two types of mortars:

(a) Heavy mortars

(b) Lightweight mortars.

(a) Heavy Mortars: Mortars having bulk density of 15 KN/m^3 or more are known as the *heavy mortars* and they are prepared from heavy quartz or other stands.

(b) Lightweight Mortars: Mortars having bulk density less than 15 KN/m^3 are known as the *lightweight mortars* and they are prepared from light porous sands from pumice and other fine aggregates.

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(ii) Kind of Binding Material: Kind of binding material for a mortar is selected by keeping in mind several factors such as expected working conditions, hardening temperature, moisture conditions etc.

- According to the kind of binding material, the mortas are classified into the following five categories:
  (i) Lime mortar
  (ii) Surkhi mortar
  (iii) Cement mortar
  (iv) Gauged mortar
  (v) Gypsum mortar

(i) Lime Mortar

- In this type of mortar, lime is used as a binding material.
- It has a high plasticity and can be placed easily.
- It possesses good cohesiveness with other surfaces and shrinks very little.
- It is sufficiently durable, but it hardens slowly.
- Lime used for mortar can be fat lime or hydraulic lime.

(a) Fat lime:

- It has high calcium oxide content.
- Its hardening solely depends on loss of water, and absorption of carbon dioxide from the atmosphere are possible recrystallization in due course.
- It shrinks to a great extent and hence it requires about 2 to 3 times its volume of sand. Therefore, it should be slaked before use.
- It is unsuitable for waterlogged areas or in damp situations.

(b) Hydrated lime:

- It is a dry powder obtained by treating quick lime with water enough to satisfy its chemical affinity for water under the conditions of its hydration.
- It contains small quantities of silica and alumina and/Iron oxide which are in chemical combination with some of calcium oxide contents, giving a putty or mortar which has the property of setting and hardening under water.
- It requires proportion of lime to sand by volume about 1:2 or so. It should be consumed within one hour after mixing.
- It possesses more strength can be used in damp situations.

- Slaked fat lime is used to prepare mortar for plastering, while hydraulic lime is used in preparing mortar for masonry construction.

(ii) Surkhi Mortar

- Surkhi is a pozzolanic material and it should be grinded such that all of it passes through a 4.75 mm IS sieve and 0-15% through 150 mm micron sieve.
- This type of mortar is prepared by using fully surkhi instead of sand or by replacing half of sand in case of fat lime mortar.
- Surkhi mortar is used for ordinary masonry work of all kinds in foundation and superstructure. It cannot used for plastering or pointing since surkhi is likely to distengrate after some time.

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(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 insert substances and hence they cannot be used as adulterants with matrix as a cement.
- Setting and hardening of cement mortar depends upon the setting and hardening of the cement-water paste which binds the particles of sand.
- When it is used for protective plaster provides a water proof layer and protects the elements covered from weathering effects (i.e. provides resistance to weathering agencies such as rain, temperature variation, frost action, etc.)
- It is used for damp-proof course below the ground level, exposed work such as exterior free standing walls and parapets, engineering construction with bricks of high strength.
- It is also used for pointing the joints of masonry, for plastering the surface of masonry to protect it from weather and to provide a pleasing and smooth finish.
- It should be immediately used after preparing and should be consumed within about 30 minutes after adding water.
- In masonry, bricks or stones should be fully saturated with water before laying them in structure otherwise, bricks or stones may absorb greater part of water from the mortar, thus making the mortar joint weaker due to lack of water required for hydration.
- Masonry or plastered surface should be continuously kept moist by sprinkling water for at least 7 days.
- Mix proportions of cement mortar are given in table below.

S.No.	Type of work	Cement	Sand
1.	Masonry	1	4-5
2.	Plastering		
	(a) Interior	1	4
	(b) Exterior	1	5-6
3.	Pointing	1	1-3
4.	Reinforced brick work	1	3
5.	Foundation	1	3-4

(iv) Gauged Mortar/Lime-Cement Mortar

- To improve the quality of lime mortar and to achieve early strength, the cement is sometimes added to it and this process is known as the gauging.
- It makes lime mortar economical, strong and dense.
- Usual proportion of cement to lime by volumes about 1:6 to 1:8.
- It is also known as the composite mortar or lime-cement mortar and it can also be formed by the combination of cement and clay.
- Lower cement content in cement mortar leads to reduction in workability, less cohesion and will produce porous joints with a tendency for low frost resistance.

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- Advantage of lime in composite mortar is that it increases the water retentivity of mortar, improve working qualities and bonding properties. In this way, early strength can also be achieved without the mature strength being too high.
- It is used for half brick walling (e.g. cavity walls), in masonary to bind stones, binds or concrete blocks, for pointing joints of masonary, and for plastering wall surfaces

(v) Gypsum Mortar

- These are prepared from gypsum binding materials such as building gypsum and anhydrite binding materials.

3. Nature of Application :

- According to the nature of application the mortars are classified into two categories.
  - (i) Bricklaying mortars
  - (ii) Finishing mortars

(i) Bricklaying mortars :

- Mortars after 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.
- Cement or lime is generally used as binding material for ordinary plastering mortar.

4. Special Mortars :

Following are the various types of special mortars which are used for certain conditions.

- (i) Fire-resistant mortar
- (ii) Lightweight mortar
- (iii) Packing mortar
- (iv) Sound-absorbing mortar
- (v) X-ray shielding mortar.

(i) Fire-resistant mortar :

- It is prepared by adding aluminous cement to the crushed power of firebricks.
- The usual proportion is 1 part of aluminous cement to 2 parts of powder of firebricks.
- It is fire-resistant and it is therefore used with firebricks for lining furnaces, fire places, ovens, etc.

(ii) Lightweight mortar :

- It is prepared by adding materials such as saw dust, wood powder etc. to the lime mortar or cement mortar.
- It is used in this sound-proof and heat-proof constructions.

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(iii) Packing mortar :

- To pack oil wells, special mortars possessing the properties of high homogeneity, water resistance, predetermined setting time, ability to form solid, water-proof plugs in cracks and voids of rocks, resistance to subsoil water pressure, etc. have to be formed.

(iv) Sound absorbing mortar :

- To reduce the noise level, the sound absorbing plaster is formed with the help of sound absorbing .Binding materials employed in its composition may be Portland cement, lime, gypsum, slag, etc.
- Aggregates are selected from lightweight porous materials such as pumice, cinders, etc.

(v) X-ray shielding mortar :

- It is used for providing the plastering coats to walls and ceiling of X-ray cabinets.
- It is a heavy type of mortar with bulk density over 22 kN/m^3.
- Aggregates are obtained from heavy rock and suitable admixture are added to enhance the protective property of such a mortar.

PROPERTIES OF 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 so that speed in construction may be achieved.
9. The joints formed by mortar should not develop cracks and they should be able to maintain their appearance for a sufficiently long period.

SELECTION OF MORTAR

No.	Nature of work	Type of Mortar	Proportions
1.	Construction work in water logged areas and exposed positions	Cement or lime mortar ime being eminently hydraulic lime	1:3
2.	Damp-proof courses and cement concrete roads	Cement mortar	1:2
3.	General R.C.C. work such as lintels, columns, slabs, stairs etc	Cement mortar, the concrete mix being 1:2:4	1:3
4.	Internal walls and surfaces of less importance or cinder.	Lime cinder mortar, Sand is replaced by ashes	1:3

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5. Mortar for laying fire bricks cement to 2 part of finely crushed powder of fire bricks	Fire resisting mortar	1 part of aluminous
6. Partition walls and parapet walls Lime mortar prop. 1:1 Lime should be moderately hydraulic lime.	Cement mortar	1:3
7. Plaster work Lime mortar	Cement mortar 1:2	1:3 to 1:4
8. Pointing work	Cement mortar	1:1 to 1:2
9. Reinforced brick work	Cement mortar	1:3
10. Stone masonry with best varieties of stones	Lime mortar Lime being eminently hydraulic lime.	1:2
11. Stone masonry with ordinary stones, brickwork, foundations, etc. Lime should be eminently hydraulic lime or moderately hydraulic lime.	Lime mortar Cement mortar	1:2 1:6
12. Thin joints in brickwork Lime being fat lime	Lime mortar	1:3

PROPERTIES OF MORTAR

Strength of Mortar

- Strength of masonry depends upon both the mortar and the brick block.
- A very strong mortar with weak brick will be of little use.
- On the other hand the use of much weaker mortar say, 1:10 cement mortar is not satisfactory since reduction in cement content leads to less workability, less cohesion and will produce porous joints of low frost resistance.
- Strength of hardened mortar depends on the activity of binding materials, the water cement ratio, consumption of binding material and the quality of sand.

Silent Points

- Strong cement mortars are most likely to lead to shrinkage cracks, and should, therefore be avoided except where high strength is an essential requirement.
- It requires about twice as much cement to produce a mortar of given strength when fine sand is used as it does with coarse sand.
- When the percentage of mixing water is increased beyond that required to form a placeable mix, the density and strength of mortar reduces.
- Mortar are also classified on the basis of their 28 days compressive strength.

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Mix Proportion and Strength of Mortars for Masonry		
S.No.	Grade of Mortar	Minimum Comprehensive Strength at 28 days in N/mm^2
(1)	(2)	(3)
1.	H1	≥10
2.	H2	7.5-6.0
3.	M1	5.0-3.0
4.	M2	3.0-2.0
5.	M3	1.5
6.	L1	0.7
7.	L2	0.5

Workability of Mortar

- Mortar should not contain excess water and it should be as stiff such that it can be conveniently used.
- Joints should be well formed and the excess mortar from joints should be neatly taken off by a trowel.

Resistance to Penetration of rain

- Mortor for plastering should protect the masonry joints and units by forming an impermeable sheet.

Mobility and Placebility

- Mobility is used to indicate the consistency of mortar.
- Placeability is the case with which the mortar mix can be applied with a minimum cost in a thin and uniform layer on the surface.
- Mortas for masonry, finishes and other works are made sufficiently mobile.
- Mobility of mortar mix determines its placeability.

Water Retention

It is ability of mortar not to stratify during transportation and to retain adequate humidity in a thin layer spread over a porous bed.

- Mortar mix of low water retention will show the defects after hardening as it may lose so much water that the amount left may be insufficient for its hardening and required strength.

GROUT

- Cement mortar of fluid consistency used to fill the voids and joints in masonry and to repair the cracks is known as grout.
- It is also used to increase the bearing capacity of soil by injection.

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- Grout finds extensive use in dams - to fill the cracks formed after the concrete sets and hardens; spaces between tunnel walls and the surrounding earth - to spread the earth stresses uniformly over the structures and; hollow concrete blocks - to develop bond between steel reinforcement and concrete.
- It differs from mortar in its fluidity as, it is to be poured and not spread into place with trowel.
- It is composed of cement, fine or coarse sand, water, and a small amount (if any) of grouting admixture.
- Water-cement ratio should be kept as low as possible to increase the strength and reduce the shrinkage.
- For wide cracks the grout is poured under pressure or pumped in the cracks. After the crack is filled, pressure is maintained for a few minutes to ensure satisfactory penetration.

GUNTING

- Application of mortar or concrete under pneumatic pressure through a cement gun is known as guniting concrete becomes extremely strong and a high bond is achieved.
- It is pneumatically forced, on a backing surface, through a nozzle where water is added at a high velocity.
- Mix leaving the nozzle at a high velocity strikes the surface to be repaired or protected. In this process the coarser particles rebound from the surface and leave on excellent bond coat of fine grout in intimate contact with the backing surface.
- A thin layer of grout builds up and acts like a cushion reducing the percentage rebound in the successive layers.

Proportion of Gunits Mixes

Nominal mix, placed in the gun Cement : Sand	Mix in place Cement : Sand
1 : 3	1 : 2.0
1 : 3.5	1 : 2.8
1 : 4.0	1 : 3.1
1 : 4.5	1 : 3.3
1 : 5.0	1 : 3.6
1 : 6.0	1 : 4.1

- Guniting is done in layer of 40-50 mm.
- A good well compacted gunite cured for 28 days gives a compressive strength as high as 42 N/mm^2.
- Average unit weight of gunite is 2300 kg/m^3.
- Curing is done for seven days.
- Gunite can be employed for construction of thin section, e.g., folded planes, shells and thin walls; linings for tunnels and swimming pools; repairing of deteriorated concrete damaged by fire. earthquake, chemicals and in hydraulic structures; strengthening buildings, bridges and jetties, stabilizing rocks and earth slopes; protective coatings over prestressing wires and steel pipes and; to furnish rough surface texture form architectural point of view.

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Institute for Engineers
IES/GATE/PSUs
Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
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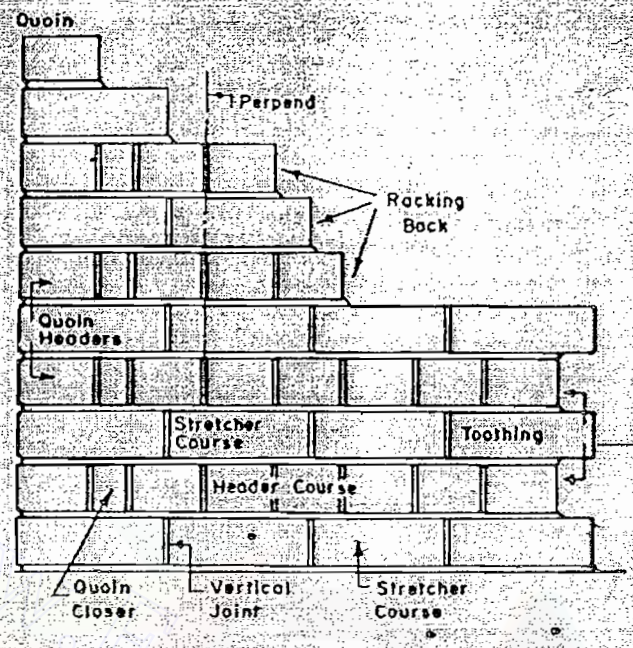
BRICK MASONARY

Basic Definitions



Elevation of a brick wall.

1. **Stretcher.**

- Stretcher is the longer face of the brick (i.e.19 cm × 9 cm).
- A course of bricks in which all the bricks are laid as stretches on facing is known as a stretcher course or stretching course.

2. **Header**

- Header is the shorter face of the brick (i.e.9 cm × 9 cm). A course of bricks in which all the bricks are laid as headers on the facing is known as header course or heading course.

3. **Lap**

- Lap is the horizontal distance between the vertical joints of successive brick courses.

4. **Prepand**

- Perpend is an imaginary vertical line which includes the vertical joint separating two adjoining bricks.

5. **Bed**

- Bed is the lower surface (19cm×9cm) of the brick when laid flat.

6. **Closer**

- Closer it is a portion of a brick with the cut made longitudinally, and is used to close up bond at the end of the course.
- It helps in preventing the joints of successive sources (higher or lower) to come in a vertical line.
- Closers may be of various types.

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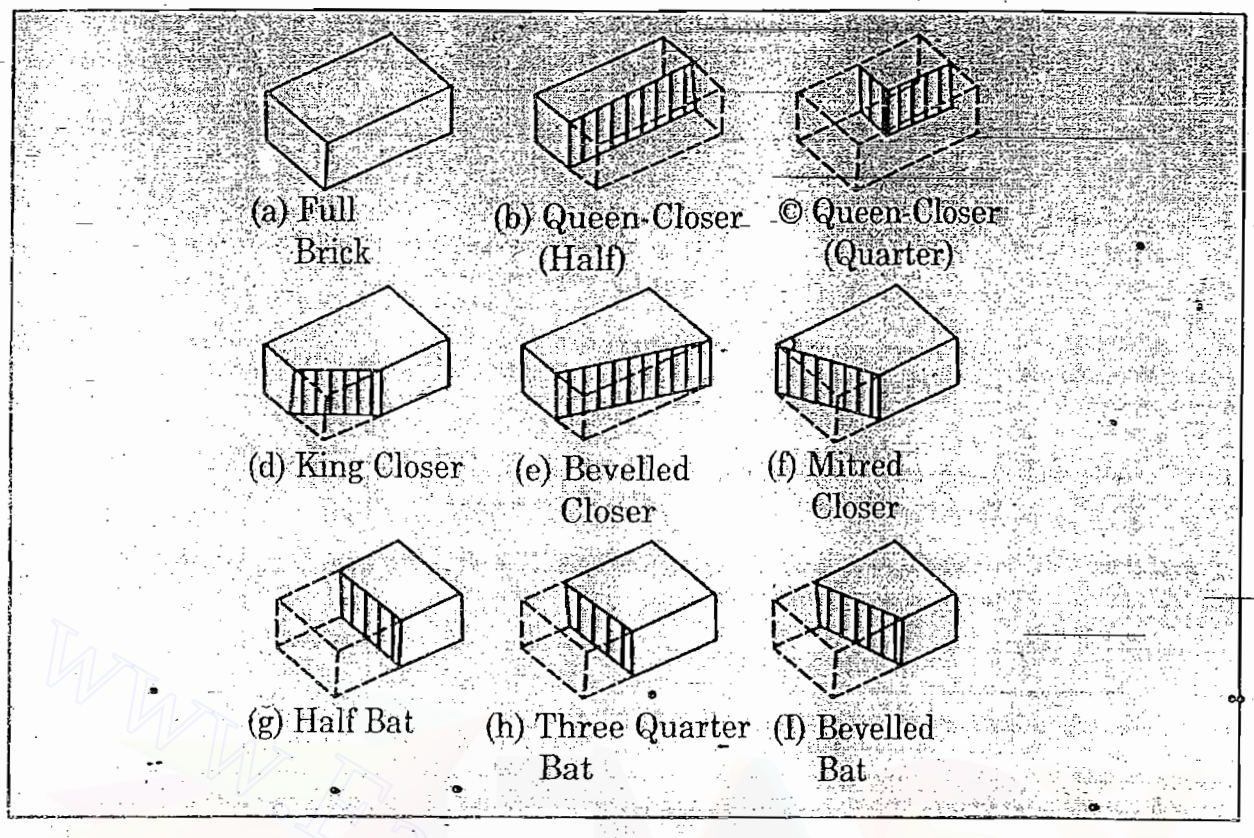

7. **Queen-closer**

- Queen-closer it is a portion of a brick obtained by cutting a brick lengthwise into two portions . thus it is a brick which is half as wide as the full brick.
- It also known as queen-closer-half.
- If a queen-closer is broken into two pieces, it is known as queen-closer-quarter, such a closer is thus a brick piece which is one-quarter of the brick size.

8. **King Closer**

- It is the portion of a brick which is such cut that width of one its end is half that of a full brick, while the width at the other end is equal to the full width .
- It is obtained by cutting the triangular piece between the centre of one end and the centre of the other (lay) side.
- It has half-header and half-stretcher face.

9. **Bevelled Closer**

- It is a special form of a king closer in which the whole length of the brick (i.e., stretcher face) is bevelled in such a way that half width is maintained at one end and full width is maintained at the other end.

10. **Mitred Closer**

- Mitred closer it is a portion of a brick whose one end is cut splayed or mitred for full width.
- Angle of splay may vary from 45° to 60°.
- One longer face of the mitred closer is of full length of the brick while the other face is smaller in length.

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11. **Bat**

- It is the portion of the brick cut across the width.
- A bat is smaller in length than the full brick.
- If length of the bat is equal to half the length of the original brick, it is known as half bat.
- A three quarter-bat is the one having its length equal to three-quarters of the length of a full brick.
- If bat has its width bevelled. It is known is bevelled bat.

12. **Arris**

- It is the edge of a brick.

13. **Bull Nose**

- It is a special moulded brick with one edge rounded or with two edge rounded.
- These are used in copings or in such positions where rounded corners are preferred to sharp arises.

14. **Splays.**

- These are special moulded bricks which are often used to form plinth.
- Splay stretcher (plinth stretcher) and splay header (plinth header).

15. **Doglege or angle.**

- It is also special form of moulded bricks which are used to ensure a satisfactory bond at quoins which are at an angle other than right angle
- Angle and lengths of the faces forming the dogleg vary according to requirements.
- These are preferred over mitred closer.

16. **Quoin.** It is a corner or their external angle on the face side of a wall. Generally, quoins are at right angles.

- But in some cases, they may be at angles greater than 90° also..

17. **Racking Back.** It is the termination of a wall in a stepped fashion.

18. **Toothing.** It is the termination of the wall in such a fashion that each alternate course at the end projects, in order to provide adequate bond if the wall is continued horizontally at a later stage.

BONDS IN BRICKS WORK

- Bond is method of arranging the bricks in courses such that individual units are tied together and vertical joints of the successive courses do not lie in same vertical line.
- Bonds of various types are distinguished by their elevation or face appearance.
- If bricks are not arranged (on bonded) properly, continues vertical joints will result in unbounded wall,
- Unbounded wall with its continuous vertical joints has little strength and stability.
- Bonds helps in distributing concentrated loads over a large areas.

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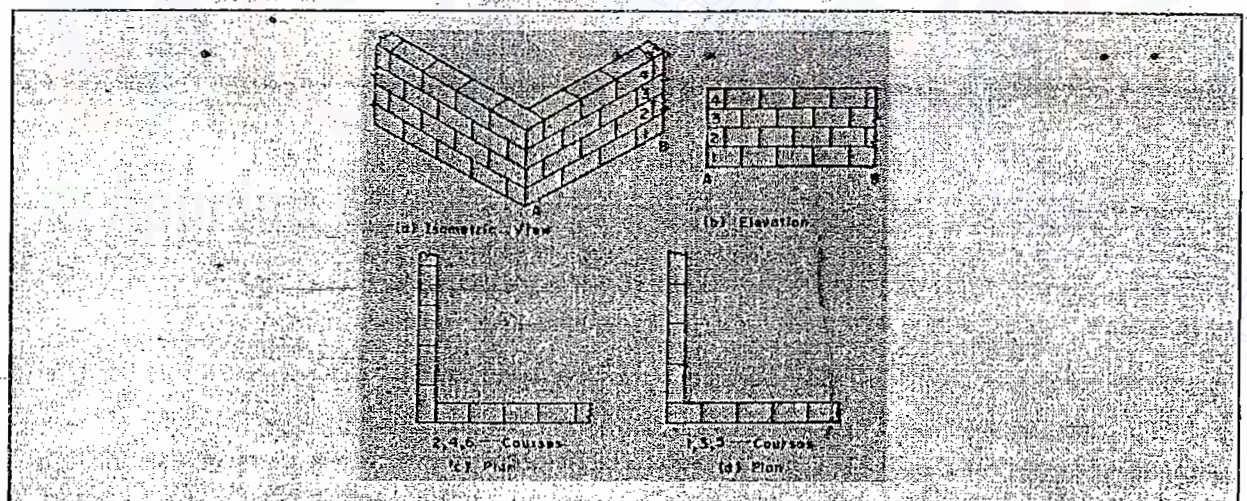
Rules of Bonding

- Bricks should be of uniform size. The length of the brick should be twice its width plus one joint, so that uniform lap is obtained. Good bond is not possible if lap is nonuniform.
- Amount of lap should be minimum $\frac{1}{4}$ bricks along the length of the wall and $\frac{1}{2}$ bricks across the thickness of the wall.
- Use of brick bats should be discouraged, except in special locations.
- Alternate course, the centre line of header should coincide with the centre line of the stretcher, in the course below or above it.
- Vertical joints in the alternate courses should be along the same perpend.
- Stretchers should be used only in the facing; they should not be used in the hearing. Hearing should be done in headers only.
- It is preferable to provide every sixth course as a header course one both the sides of the wall.

Types of Bonds

1. Stretcher bond.
2. Header bond.
3. English bond.
4. Flemish bond.
5. Facing bond.

1. Stretcher Bond.



Stretcher bond

- Stretcher bond or stretching bond is one in which all the bricks are laid as stretchers on the faces of walls.
- This pattern is used only for those walls which have thickness of half brick (i.e. 9cm). Such as partition walls, sleeper walls, division walls or chimney stacks.

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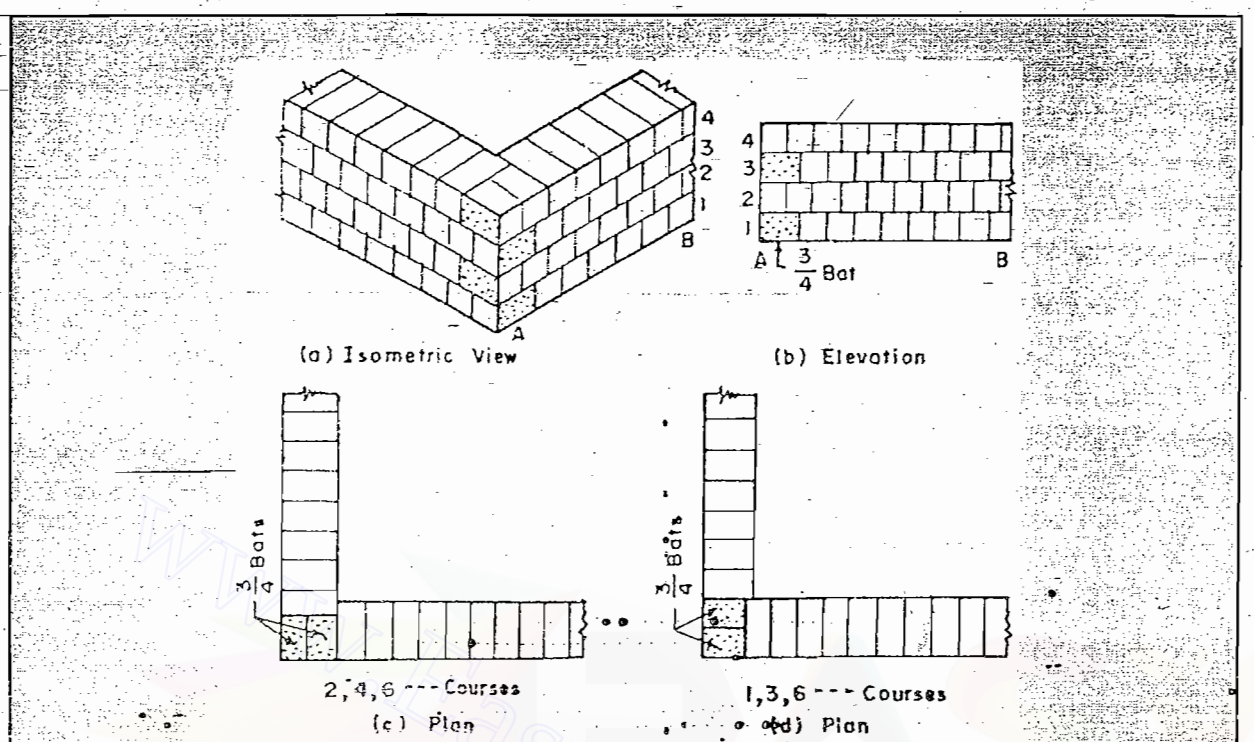
- This bond is not possible if the thickness of the wall is more than 1/2 brick.

2. Header Bond



Header bond.

- Header bond or heading bond is the one in which all the bricks are laid as headers on the faces of walls.
- Width of the brick are thus along the direction of the wall.
- Pattern is used only when the thickness of the wall is equal to one brick (i.e. 19 cm).
- Overlap is usually kept equal to half the width of brick (i.e $4\frac{1}{2}$ cm).
- This is achieved by using three-quarter brick bats in each alternate courses as quoins.
- This bond does not have strength to transmit pressure in the direction of the length of the wall. As such it is unsuitable for load bearing walls.
- It is useful for curved brick work where the stretchers, if used, would project beyond the face of the wall and would neccessitate inconvenient cutting.
- It is also use din construction of footings.

English Bond

- This is most commonly used wall, for all wall thickness and considered to be strongest.
- This bond consists of alternate courses of headers and stretchers.

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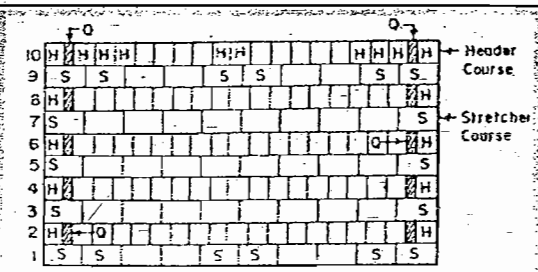
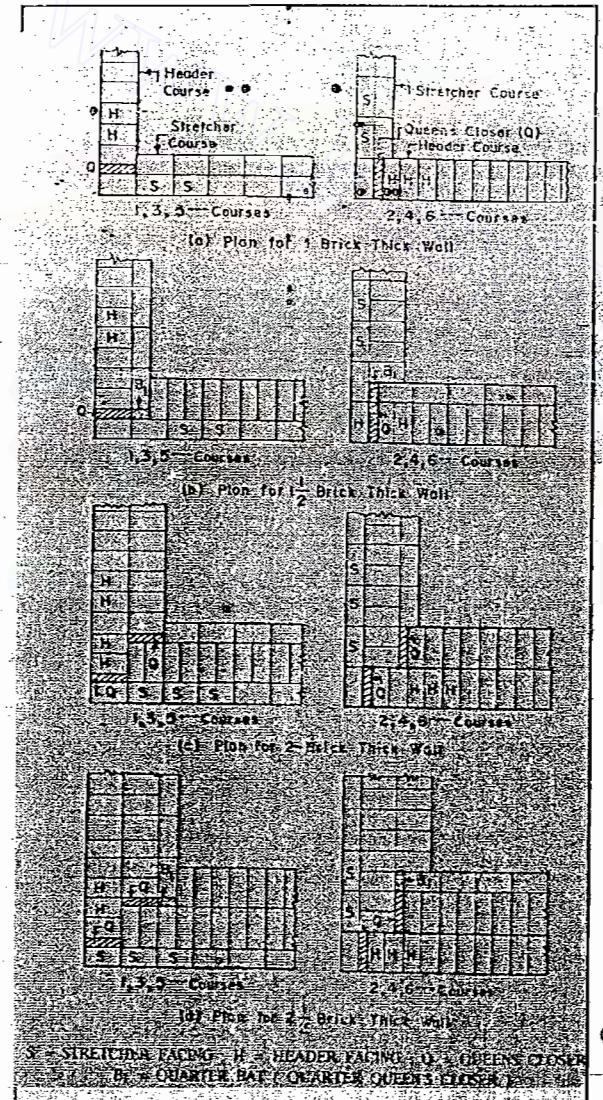
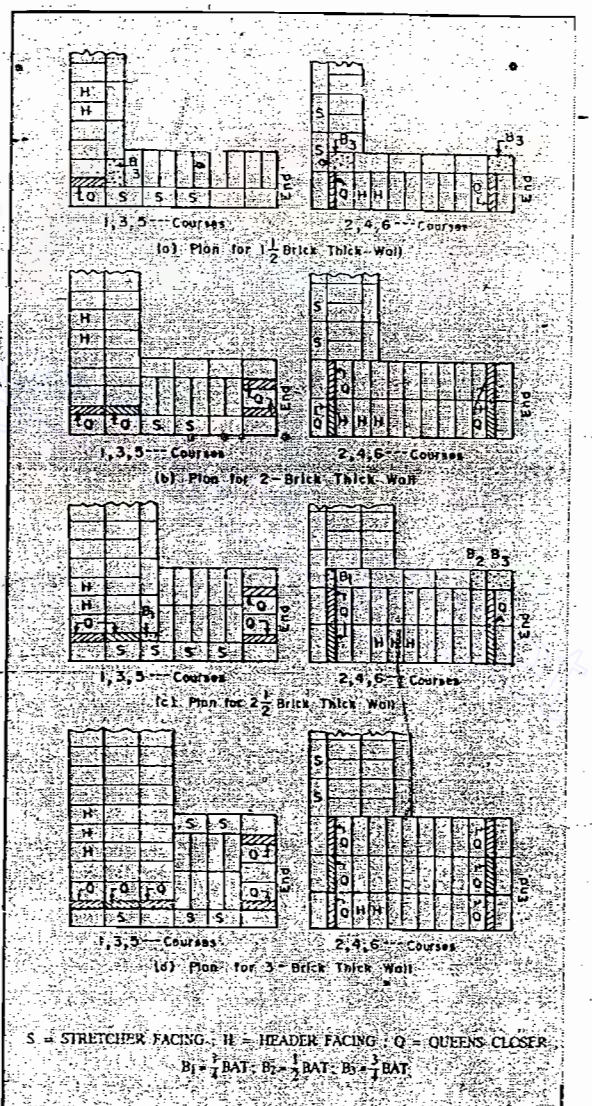


English bond

- In this bond joints of header course come over each other, similarly joints of stretcher course come over each other.
- A queen closer is used after first header (qunion header) in each header course to break vertical joints in successive courses.
- Only headers are used for hearting of thicker walls.



English bond.



English bond (alternative arrangements).

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Institute for Engineers
IES/GATE/PSUs
Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
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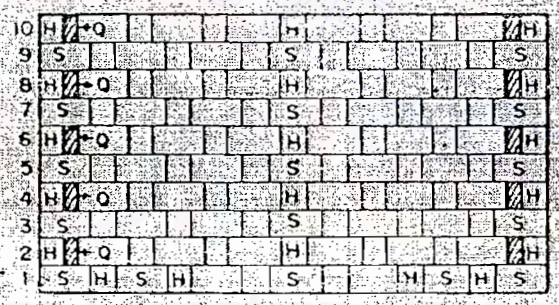
Important Point

- Alternative courses will show either headers or stretchers in elevation.
- Every alternate header comes centrally over the joint between two stretchers in course below.
- In stretcher course, the stretchers have a min. lap of $\frac{1}{4}$th their length over headers.
- There is no continuous vertical joint.
- Walls of even multiple of half bricks (i.e. $1\frac{1}{2}$ brick thick wall, $2\frac{1}{2}$ brick thick wall etc. will show stretchers on once face and headers on the other face.
- Hearing (middle portion) of each of the thicker walls consists entirely of headers.
- Atleast every alternate transverse joint is continuous from face to face.
- Header course should never start with queen's closer, as it will get displaced therefore. queen's closer should be placed just next to the quoin header.
- Queen's closers are not required in stretcher courses.
- Number of vertical joints in the header course are twice the number of vertical joints in the stretcher course.
- Joint in the header course are made thinner than the joints in the stretcher course.

4. Flemish Bond



FLEMISH BOND (ELEVATION)

- In this type of joint each course is made up of alternate header and stretchers.
- Every alternate course starts with a header at corner i.e union header.
- Qunion closers are placed next to qunion header in alternate course to form face lap.
- Every header is centrally supported by streacher below it.
- Types of Flemish bond
  - (a) Double Flemish bond.
  - (b) Single Flemish bond

(a) Double Flemish bond

- In this bond, back and front face are same in appearance.

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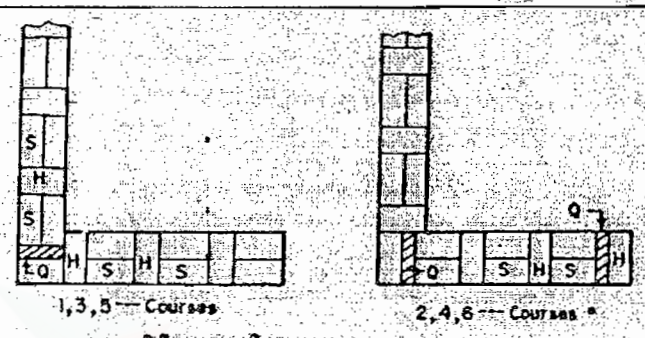
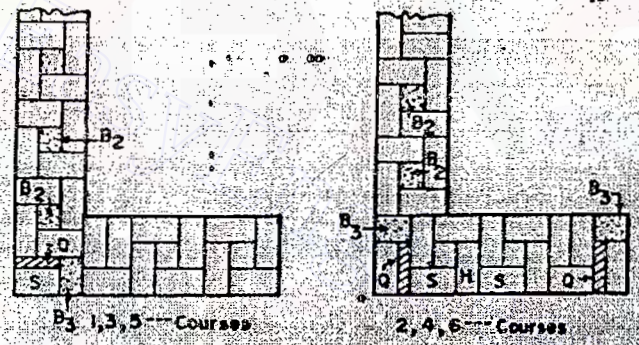
Important points

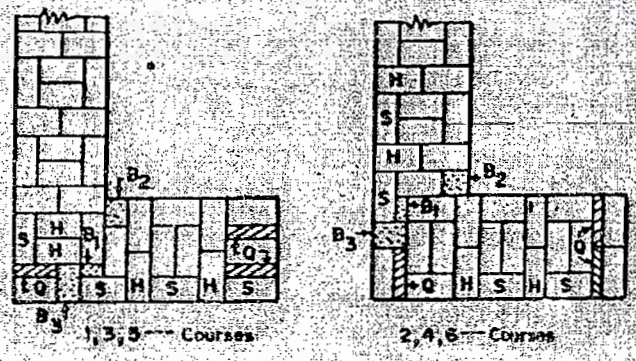
- Each course has alternate header and stretcher. Therefore it gives better appearance than English bond.
- Qunion closer are placed next to qunion headers in every alternate course.
- Walls having thickness equal to odd multiple of half bricks, half bats and three-quarter bats are usually used.
- Walls having thickness equal to even multiple of half bricks, no bats are required. A header or stretcher will comes out as header or stretcher on the same course in front as well as back faces.



(a) Plan for one Brick Thick Wall



(b) Plan for $1\frac{1}{2}$ Brick Thick Wall



(c) Plan for 2 Brick Thick Wall

S = STRETCHER ; H = HEADER ; Q = QUEENS CLOSER ;
B_2 = HALF BAT ; $B_3 = \frac{3}{4}$ BRICK ; B_1 = QUARTER BAT

Double flemish bond.

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Institute for Engineers
IES/GATE/PSUs
Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
Phone: 011-41013406, 7838813406, 9711853908

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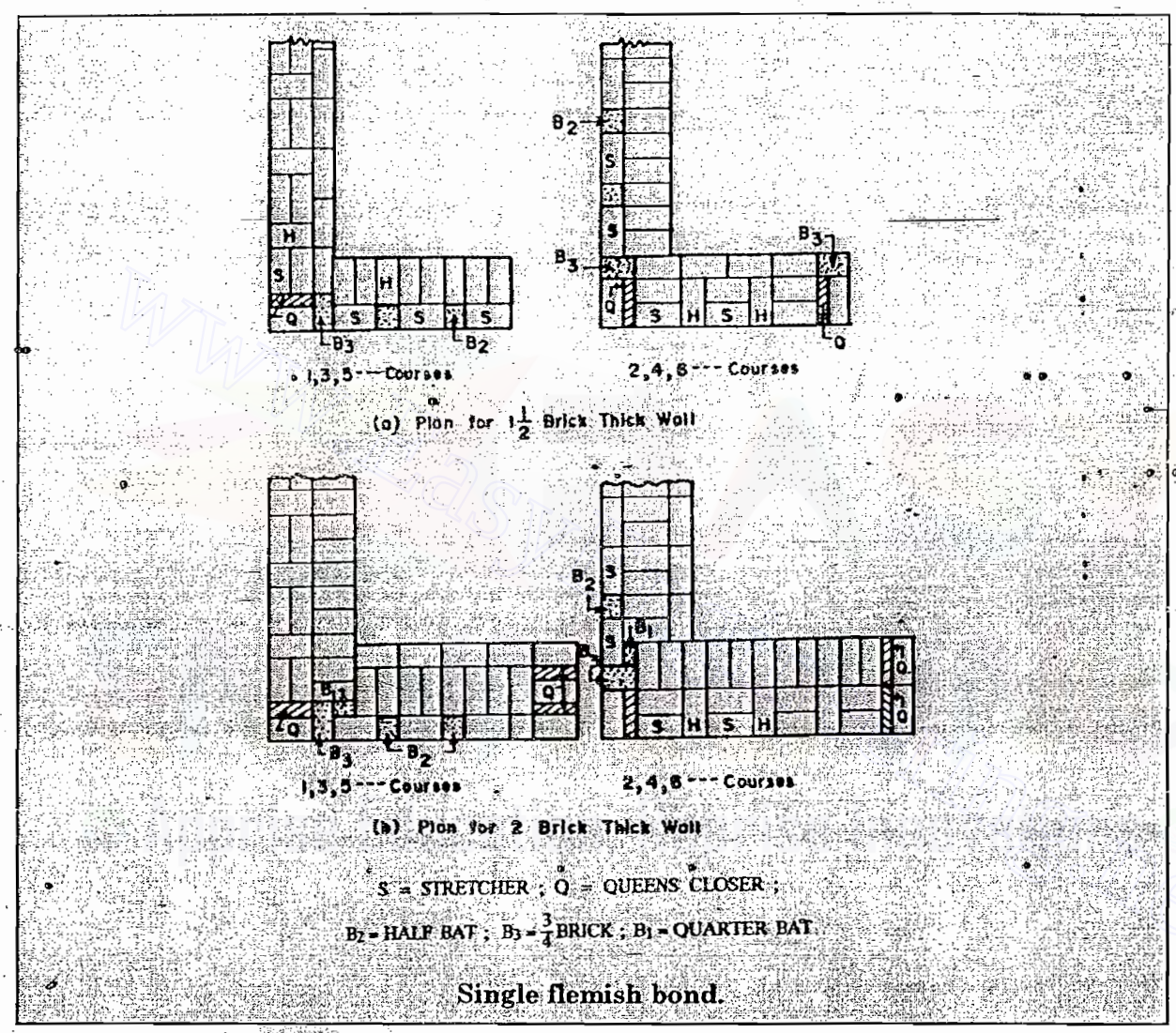
Single Flemish bond

- In this bond Facing has appearance of double flemish bond and, backing of English bond and hearting in each course.
- This bond thus uses strength of the English bond and appearance of flemish bond.
- This bond can be used for those walls having thickness at least equal to $1\frac{1}{2}$ brick.
- Double flemish bond facing is done with good quality expensive bricks.
- Cheaper bricks can be used for backing and hearting.



Single flemish bond.

COMPARISON OF ENGLISH BOND AND FLEMISH BOND.

- English bond is stronger than flemish bond for walls thicker than $1\frac{1}{2}$ brick.
- Flemish bond gives better appearance than the English bond.
- Broken bricks can be used in the form of bats in Flemish bond. But, more mortar is required.
- Construction with Flemish bond requires greater skill in comparison to English bond.

I.E.S-MASTER
Institute for Engineers
IES/GATE/PSUs
Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
Phone: 011-41013406, 7838813406, 9711853908

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5. Facing Bond

- This bond is used where bricks of different thickness are to be used in the facing and backing of the wall.
- In this bond, a header course is provided after several stretcher courses.
- As the thickness of bricks are different in the facing and backing the vertical distance between the successive header course is kept equal to the least common multiple of thickness of backing and facing bricks.
- This type of bond is not structurally good and load distribution is not uniform.

DEFECTS IN BRICK MASONARY

- Brick masonary may develops defects due to following reasons.

  (i) Sulphate attack

  (ii) Crystallization of salts from bricks (efflorescence)

  (iii) Corrosion of embedded fixtures.

  (iv) Drying shrinkage.

1. Sulphate attack.

- It is common defect, specially at locations where the brick work is either exposed (such as in boundary walls, unplastered external walls etc.) or where brick work is likely to come in contact with moisture.
- Sulphate salts present in brick react with hydraulic lime in the case of lime mortar and with alumina of cement in the case of cement mortar.
- Due to this reaction, the increase in the volume of mortar takes place, resulting in chipping and spalling of bricks. Cracks are formed in joints and rendering.

2. Crystallization of salts from bricks.

- If the bricks are manufactured from earth containing excessive soluble salts, entry of moisture, either due to dampness or due to rains etc, dissolves the soluble salts.
- Salts, after getting dissolved in water, appear in the form of fine whitish crystals on the exposed brick surface. This is known as efflorescence.
- This situation can be improved by brushing and washing on the affected surface from time to time.

3. Corrosion of embedded fixtures

- Iron or steel fixtures, such as the pipes or holdfasts of doors windows etc. embedded in brick masonry gets corroded with time specially when lime mortar is used.
- Corrosion results in the increase in the volume, resulting in cracks in brick masonry. Therefore these figures should be well-embedded in cement mortar.

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3. **Drying shrinkage**

- When moisture penetrates the brick work, it swells.
- On evaporation of moisture during the drying, due to atmospheric heat etc., the bricks shrinks, resulting in the development of cracks in the masonry joints.

STRENGTH OF BRICK MASONARY

- Strength of brick masonary depend on following factors.

1. Type and quality of bricks
2. Mortar mix proportion.
3. Size and shape of masonry construction.

1. Type and quality of bricks

- Strength of brick masonry primarily depends upon the type and class of bricks used, and the basic compressive strength of bricks.
- Before designing the brick masonry structures, it is essential to determine the compressive strength of brick units.

2. Mortar mix proportion

- Type of mortar and mix proportions another important factor which determines the strength of masonry.

3. Size and shape of masonry construction

- Strength of brick masonry walls depends upon
  (i) slenderness greater ratio of masonry,
  (ii) shape factor.

1. ***Slenderness Ratio:***

- For a wall, the *slenderness ratio* is taken as the effective height of the wall divided by its effective thickness or the effective length divided by the effective thickness, whichever is less.
- For a column, the slenderness ratio is equal to the effective height divided by the corresponding lateral dimension (thickness or width).

Maximum Slenderness ratio for a Load Bearing Wall

No. of Storeys	Maximum Slenderness Ratio	
	Using Portland Cement or Portland Pozzolana Cement in Mortar	Using Lime Mortar
Not exceeding 2	27	20
Exceeding 2	27	13

- For load bearing column slenderness ratio shall not exceed 12.
- Under a vertical load a wall would buckle either around a horizontal axis parallel to the length of the wall or around a vertical axis.

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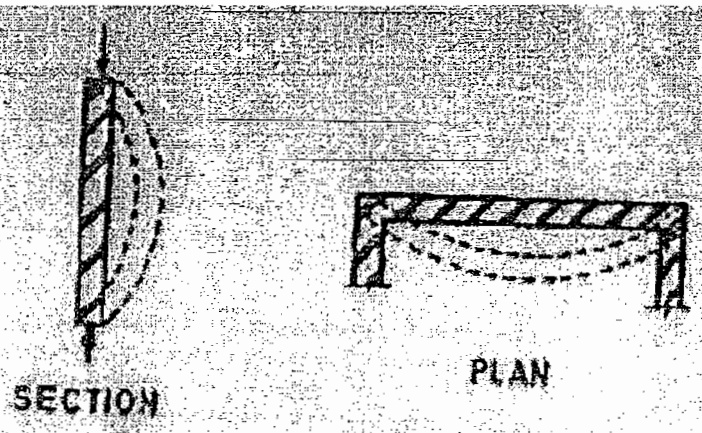

Section : Section of a wall with Tendency to Buckle Around Horizontal Axis under Vertical Load.

Plan : Plan view of a wall with Tendency to Buckle Around Vertical Axis under Vertical Load

Buckling of Walls

- Buckling is resisted by horizontal supports such as floors and roofs, as well as by vertical supports such as cross walls, piers and buttresses.
- Hence capacity of the walls to take vertical loads depends both on horizontal supports that is, floor or roof as well as on vertical supports that is, cross walls, piers and buttresses.
- But for the sake of simplicity and taking on safe side, lesser of the two slenderness ratios, namely, one derived from height and the other derived from length is taken into consideration for determining permissible stresses in masonry walls.
- Limiting values of SR are less for masonry built in lime mortar, as compared to that built in cement mortar, because the it is relatively weaker, is more liable to buckling.
- Values of maximum SR are less for taller buildings since imperfections in workmanship in regard to verticality are likely to be more pronounced in case of taller buildings.
- Limiting values of SR for column is less than that of walls because a column can buckle around either of the two horizontal axes, while walls can buckle around horizontal axis only.

2. Shape Factor

- Shape factor takes into account the effect of shape of the brick, *i.e.* ratio of its height to thickness.

Ratio of height to thickness of brick or block	Factor
0.75	1.0
1.0	1.2
1.5	1.6
2.0 to 3.0	2.0

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PERMISSIBLE COMPRESSIVE STRESS OF BRICK MASONARY

Basic compressive stresses for masonry members

S.N.	Description of mortar	Mix (Parts by volume)					Hardening time after completion of work	Basic compressive stress in kg/cm² corresponding to masonry units having crushing strength (kg/cm²)					
		Cement	Lime	Lime-Pozzolana	Pozzolana	Sand		35	70	105	140	175	210
1.	Cement	1	$0-\frac{1}{4}$ (C)	—	—	3	7	3.5	7.0	10.5	12.5	14.5	16.5
2.	Cement	1	$\frac{1}{2}$(C)	—	—	$4\frac{1}{2}$	14	3.5	7.0	10.0	11.5	13.0	14.5
3.	Cement-lime	1	1(C)	—	—	6	14	3.5	7.0	10.0	11.0	12.0	13.0
4.	Cement-lime	1	2(B)	—	—	9	14	3.5	5.5	8.5	10.0	11.0	12.0
5.	Cement	1	—	—	—	6							
6.	Lime-Pozzolana mixtured	—	—	1	—	1.5							
7.	Cement-lime	1	3(B) or (C)	—	—	12	14	2.5	5.0	7.0	8.0	9.0	10.0
8.	Hydraulic lime	—	1(A)	—	—	2	14	2.5	5.0	7.0	8.0	9.0	10.0
9.	Lime-pozzolana	—	1(C)	—	1	2							
10.	Lime	—	1(B)	—	—	3	28	2.5	4.0	5.5	6.0	6.5	7.0

- Above table gives permissible compressive stress for brick masonary using bricks of various types of mortars.
- Permissible compressive stresses recommended in the table apply to masonry walls consisting of squared units built to horizontal courses, with broken vertical joints.
- Effects of slenderness ratio and shape factor should be taken into consideration.
- This table is valid for slenderness ratio 6 and loading with zero eccentricity.
- Linear interpolation is permissible for units whose crushing strengths are intermediate between those given in the table.
- Lime classification (classes A, B and C) and building lime shall conform to accepted standards.
- For mortar under serial No. 6, lime pozzolana mixture shall be of grade *LP* 40 conforming to accepted standards.

PERMISSIBLE TENSILE STRESS OF BRICK MASONARY

- Tensile strength of brick work in bending shall not be more than 1 Kg/cm² (0.1 N/mm²) for mortars not weaker than 1 : 1 : 6 : : cement : Lime : Sand mix.

PERMISSIBLE SHEAR STRESS IN BRICK MASONARY

- For walls built in mortar not weaker than 1 : 1 : 6 : : cement : lime : sand mix and resisting horizontal forces in plane of wall, permissible shear stress shall be taken as 1.5 Kg/cm² (0.15 N/mm²).

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THICKNESS OF A BRICK WALL

- Thickness of a brick wall depends upon the following :
  - Super-imposed load per unit length of the wall,
  - Overall height of the wall,
  - Height of the wall between floors
  - Length of the wall between piers, buttresses, crosswalls (*i.e.*, lateral support conditions).
  - Strength of brick masonry, which depends upon the quality of bricks, quality of mortar and method of bonding.

Points to be Considered

- Height of each storey is not more than 4.8 m.
- The *length of wall* is the length measured between buttresses or cross-walls, which are properly bonded to the main wall, so that sufficient lateral support is available.
- The thickness of wall should not be less than 1/6 of the storey height.
- For basement walls, the thickness should not be less than one-third the height of retained soil above basement level, nor should it be less than the thickness of wall at ground floor plus 10 cm.
- Above is applicable for walls built of bricks of concrete blocks, using lime mortar (1 : 3), or cement mortar (1 : 6) or composite mortar (1 : 2 : 9).

Minimum thickness of external and partition masonary walls of residential and business buildings

Storey above ground	Height of wall in metres above plinth level		Length of wall (m)	Thickness of wall (cm)							
	Exceeding (m)	Not exceeding (m)		Basement Floor	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Fifth Floor	Sixth Floor
1	–	3.5	Any	30	20						
1	3.5	5.0	Any	40	30						
1	5.0	6.5	Any	50	40						
2	–	6.5	Under 10	30	20	20					
2	–	6.5	Over 10	40	30	20					
2	6.5	9.5	Under 10	40	30	30					
2	6.5	9.5	Over 10	50	40	30					
3	–	10.0	Under 10	40	30	20	20				
3	–	10.0	Over 10	50	40	30	20				
3	10.0	13.5	Under 10	50	40	30	30				
3	10.0	13.5	Over 10	60	50	40	30				
4	–	13.5	Under 10	50	40	30	30	20			
4	–	13.5	Over 10	60	50	40	30	30			
4	13.5	18.0	Under 10	60	50	40	30	30			
4	13.5	18.0	Over 10	70	60	50	40	30			
5	–	16.5	Under 10	60	50	40	30	30	30		
5	–	16.5	Over 10	70	60	50	40	30	30		
5	16.5	23.0	Under 10	70	60	50	40	30	30		
5	16.5	23.0	Over 10	80	70	60	50	40	30		
6	–	20.0	Under 10	70	60	50	40	30	30	30	
6	–	20.0	Over 10	80	70	60	50	40	30	30	
6	20.0	27.5	Under 10	80	70	60	50	40	40	30	
6	20.0	27.5	Over 10	90	80	70	60	50	40	30	
7	–	23.5	Under 10	80	70	60	50	40	30	30	30
7	–	23.5	Over 10	90	80	70	60	50	40	30	50
7	23.5	32.0	Under 10	90	80	70	60	50	40	40	30
7	23.5	32.0	Over 10	100	90	80	70	60	50	40	30

IMPORTANT DEFINITIONS

Column : An isolated vertical load bearing member, width of which doesn't exceed four times the thickness.

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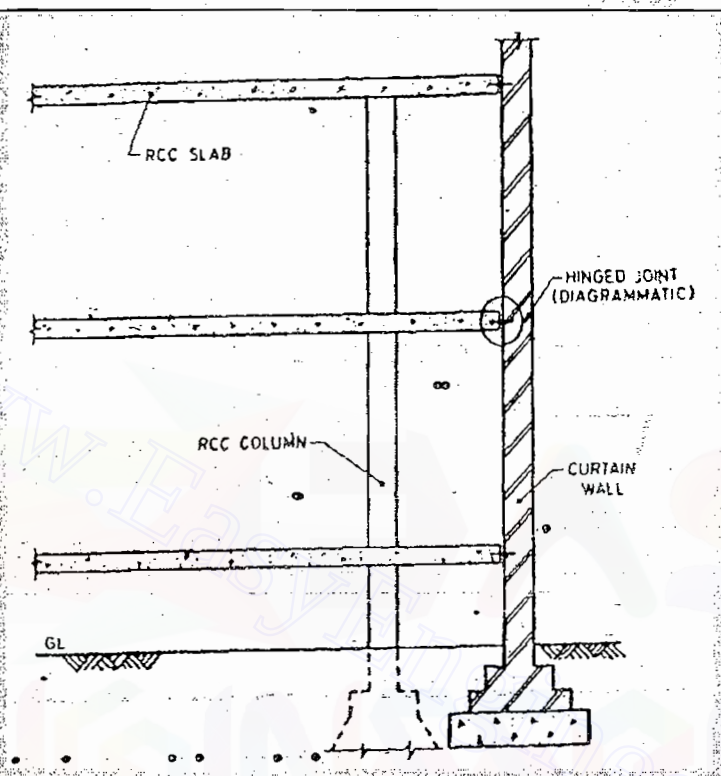
Pier - A thickened section forming integral part of a wall placed at invertals along the wall, to increase the stiffness of the wall or to carry a vertical concentrated load. Thickness of a pier is the overall thickness. Including the thickness of the wall.

Buttress - A pier of masonry built as an integral part of wall and projecting from either or both surfaces, decreasing in cross-sectional area from base to top.

Curtain Wall - A non-load bearing wall subject to lateral loads. It may be laterally supported by vertical or horizontal structural members, where necessary.



Masonary Curtain Wall

Lateral Support - A support which enables a masonary elements to resist lateral load and/or restrains lateral deflection of a masonry element at the point of support.

Load Bearing Wall - A wall designed to carry an imposed vertical load in addition to its own weight, together with any lateral load.

Partition Wall - As interior non-load bearing wall, one storey or part storey in height.

Panel Wall - An exterior non-load bearing wall in trammed construction, wholly supported at each storey but subjected to lateral loads.

Shear Wall : A wall designed to carry horizontal forces acting in its plane with or without vertical imposed loads.

Cavity Wall : A wall comprising two leaves, each leave being built of masonry units and separated by a cavity and tied together with metal ties or bonding units to ensure that the two leaves act as one structural unit, the space between the leaves being either left as continuous cavity or filled with a non-load bearing msulating and waterproofing material.

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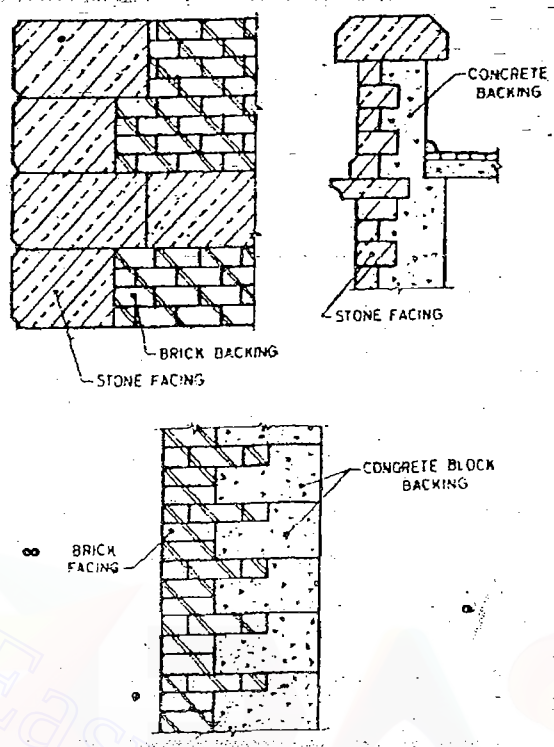
Faced Wall : A wall in which facing and backing of two different materials are bonded together to ensure common action under load.



Typical Faced Wall

Note: To ensure monolithic action in faced walls, shear strength between the facing and the backing shall be provided by toothing, bonding or other means.

Veneered Wall : A wall in which the facing is attached to the backing but not so bonded as to result in a common action under load.

CONVENTIONAL QUESTIONS

1. Illustrate with neat sketches the laying of bricks in English Bond in a right angle corner in a one and half brick thick wall. Briefly mention the important specifications to be follow. **(1990)**
2. Describe the main features of English and Flemish bonds. Draw neat sketches of two consecutive courses of a right angle corner of a two brick thick wall in English bond. **(1992)**
3. Enumerate various factors which determine the thickness of brick walls. Give the characteristcs of good bricks and name the tests that are carried out to determine them.

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OBJECTIVE QUESTIONS

1. King closers are related to
   (a) doors and windows (b) king post truss
   (c) queen post truss (d) brick masonry

2. For one cubic metre of brick masonry, the number of modular bricks needed is
   (a) 400 or less (b) 400 to 450
   (c) 500 to 550 (d) 600 to 650

3. In brick masonry,
   (a) mortar strength should match brick
   (b) mortar strength should exceed brick strength
   (c) brick strength should exceed mortar strength
   (d) the strengths of masonry and brick are independent

4. When the corner of a brick is removed along the line joining midpoints of adjoining sides, the portion left is called
   (a) closer (b) squint brick
   (c) queen closer (d) king closer

5. The number of bricks required per cubic metre of brick masonry is.
   (a) 400 (b) 450
   (c) 500 (d) 550

6. Which type of brick masonry bond is provided for heavy loads on masonry?
   (a) English bond (b) Zigzag bond
   (c) Single Flemish bond (d) Double Flemish bond

7. For flatly laid single brick soling, what is the number of bricks required of nominal size 20 cm × 10 cm × 10 cm with 1.2 cm wide cement mortar all around and with allowing up to 1% wastage for 10 m^2 area?
   (a) 400 (b) 410
   (c) 425 (d) 440

8. For high class brick masonry, which are the proper bricks?
   (a) Refractory bricks (b) Jhumb bricks
   (c) Bull nose bricks (d) Modular bricks

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9. Modular bricks are of nominal size 20 × 10 × 10 cm and 20% of the volume is lost in mortar between joints. Then what is the number of modular bricks required per cubic meter of brickwork?

(a) 520 (b) 500

(c) 485 (d) 470

10. Consider the following statements:

1. Strength of brick masonry is influenced by type of mortar.
2. Brick masonry with lime mortar achieves full strength earlier than cement mortar masonry.
3. Mortar strength decides the strength of masonry.

Which of these statements is/are correct?

(a) 1,2 and 3 (b) 1 only

(c) 1 and 3 only (d) 3 only

11. Consider the following statements:

Bricks are soaked in water before use in masonary work

1. to remove dust
2. to remove air voids
3. so that they do not absorb water from cement mortar

Which of these statements is/are correct?

(a) 1,2 and 3 (b) 1 only

(c) 2 and 3 (d) 3 only

12. The mortar used for masonry construction are classified based on strength in IS : 2250 and IS : 1905 according to their designations L_1, L_2, H_1, H_2, M_1, M_2. The correct sequence of increasing order of their strength is

(a) L_1, L_2, H_1, H_2, M_1, M_2 (b) L_2, L_1, M_2, M_1, H_2, H_1

(c) M_1, M_2, H_1, H_2, L_1, L_2 (d) L_2, L_1, M_1, M_2, H_1, H_2

13. The slenderness ratio for masonry walls should NOT be more than

(a) 50 (b) 40

(c) 30 (d) 20

14. Brick masonry walls and columns of a building are to be protected from earthquake. The earthquake proofing is done by providing

(a) cross walls (b) less openings

(c) under-reamed piles (d) a steel band at corners above windows below ceiling

15. When a beam or truss is placed on a masonry wall, it is supported on bed stone or plate. The bed stone or bed plate is necessary to

(a) add to aesthetic appearance (b) transfer the reaction over a larger contact area

(c) increase stability of beam or truss (d) prevent outward thrust on the wall

16. The maximum permissible slenderness ratio for masonry walls is

(a) 40 (b) 30

(c) 20 (d) 10

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17. In some brick masonry walls, patches of whitish crystals were found on the exposed surfaces, also chipping and spalling of bricks took place from the same walls. Which among the following are the causes of these defects?

1. Settlement of foundation
2. Over-loading of the walls
3. Sulphate attack
4. Efflorescence

Select the correct answer from the codes given below:

(a) 1 and 2 (b) 2 and 3
(c) 2 and 4 (d) 3 and 4

18. When a column is supported throughut its length either by masonry walls or by construction on all the sides, then its slenderness ratio is

(a) Infinite (b) Zero
(c) Reasonably high (d) Low

19. The minimum wall thickness of any load bearing wall in case of public building built with mortar, as per IS code, should be not less than

(a) $\frac{1}{2}$ (b) 1 brick
(c) $1\frac{1}{2}$ brick (d) 2 brick

20. Maximum slenderness ratio for load-bearing masonry wall built in cement mortar, as per IS code, shall not exceed

(a) 13 (b) 20
(c) 27 (d) 30

21. As per masonry code, the stiffening coefficient for walls stiffened by piers, buttresses or intersecting walls can be

(a) 0 to 1.0 (b) 1.0 to 2.0
(c) Greater than 2.0 (d) Invariantly 1.0

22. Consider the following statements:

Cement mortars richer than 1 : 3 are not usd in masonry work because

1. There is no gain in strength of masonry
2. There is high shrinkage.
3. They are prone to segregation

Which of these statements are correct?

(a) 1,2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

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23. If the effective length, effective height and effective thickness of a masonry wall are l, h and t respectively, then the slenderness ratio of the wall shall be

(a) $\frac{l}{t}$ (b) $\frac{h}{t}$

(c) Larger of $\frac{l}{t}$ and $\frac{h}{t}$ (d) Smaller of $\frac{l}{t}$ and $\frac{h}{t}$

24. Why are bricks soaked in water before using the brick masonry?

(a) For removing dust

(b) For reducing air voids

(c) For preventing depletion of moisture from mortar

(d) For reducing efflorescence

The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason(R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes :

(a) Both A and R are true and R is the correct explanation of A

(b) Both A and R are true but R is not a correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

25. **Assertion (A) :** For identical strength, a composite cement-lime mortar is preferred over cement mortar.

Reason (R) : Composite cement-lime mortar has higher drying shrinkage than cement mortar.

26. **Assertion (A) :** Facing bond is used when the bricks of different thicknesses are to be used in the facing and backing of the wall.

Reason (R) : Facing bond is structurally good and results in uniform distribution of load.

27. **Assertion(A) :** The volume of mortar needed for plastering on both faces of a one-brick wall is more than that for the same area on both faces together of any other thickness of brick wall.

Reason (R): More water evaporates from the wetted bricks in case of a one-brick wall and also the joints have to be more commonly raked.

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ANSWERS

1.	(d)	8.	(d)	15.	(b)	22.	(b)
2.	(c)	9.	(a)	16.	(b)	23.	(d)
3.	(a)	10.	(c)	17.	(d)	24.	(c)
4.	(d)	11.	(d)	18.	(d)	25.	(c)
5.	(c)	12.	(b)	19.	(b)	26.	(c)
6.	(a)	13.	(c)	20.	(c)	27.	(c)
7.	(c)	14.	(d)	21.	(b)		

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CHAPTER

6

Aggregates

INTRODUCTION

- Aggregates are the materials basically used as filler with binding material in the production of mortar and concrete.
- They give body to the concrete and occupy 70 to 80 percent of volume of concrete. Therefore, they exert considerable impact on the characteristics and properties of concrete.
- They are derived from igneous, sedimentary and metamorphic rocks or manufactured from blast furnace slag, etc.
- They should be clean, hard, strong, durable and graded in size to achieve utmost economy from the paste.
- Earlier aggregates were considered to be chemically inert but the latest research has revealed that some of them are chemically active and also that certain types exhibit chemical bond at the interface of aggregates and cement paste.
- To increase the bulk density of concrete aggregates are used in two different sizes—the bigger ones known to be coarse aggregate (grit) and the smaller ones fine aggregate (sand).
- Coarse aggregate form the main matrix of concrete and fine aggregate from the filler matrix between the coarse aggregate.

CLASSIFICATION OF AGGREGATE

1. On the Basic of Geological Origin

(a) Natural Aggregates

- Natural aggregates are obtained by crushing from quarries of igneous, sedimentary or metamorphic rocks.
- Most widely used aggregate are from igneous origin.
- Aggregates obtained from pits or dredged from river most often are not clean enough or well graded to suit the quality requirement. They therefore require sieving and washing before they can be used in concrete.

(b) Artificial Aggregates

- Broken bricks, blast furnace slag and synthetic aggregates are artificial aggregates.
- Broken bricks called as *brick bats* are suitable for mass concreting, for example, in foundation bases. They are not used for reinforced concrete works.

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- Blast furnance slag aggregate is obtained from slow cooling of the slag followed by crushing.
- These dense and strong aggregates as obtained are used for making precast concrete products.
- The blast furnace slag aggregate has good fire resisting properties but are responsible for corrosion of reinforcement due to sulphur content of slag.
- Synthetic aggregates are obtained by thermally processed materials such as expanded clay and shale used for making light weight concrete.

2. On the Basis of Size

(a) Coarse Aggregate

- Aggregates ranging from 80mm – 4.75mm are identified as coarse aggregates.
- These are obtained from natural disintegration or artificial crushing of rocks.

Note:
- Size of coarse aggregates depends on the thickness of section (member), reinforcement spacing, clear cover, mixing handling and placing methods.
- For reinforced sections the maximum size should be at least 5 mm less than the clear spacing between the reinforcement and also at least 5mm less than the clear cover. Aggregate more than 20 mm size are seldom used for reinforced cement concrete structural.

(b) Fine Aggregate

- Aggregate passing through 4.75 mm sieve are defined as fine.
- They may be natural sand—deposited by rivers, crushed stone sand—obtained by crushing stones and crushed gravel sand.
- Smallest size of fine aggregate (sand) is 0.06 mm.
- Depending upon the particle size, fine aggregates are described as fine, medium and coarse sands.

3. On the Basis of Shape

(a) Rounded aggregates:

- These are usually obtained from river or sea shore.
- These have minimum ratio of surface area to the volume.
- Cement paste required is minimum and produce minimum voids (about 32%) in concrete.

(b) Irregular aggregates.

- They have voids about 36 per cent and require more cement paste as compared to rounded aggregate.
- Due of irregularity in shape they develop good bond and are suitable for making ordinary concrete.

(c) Angular Aggregate

- These have sharp, angular and rough particles having maximum voids (about 40 per cent).
- Angular aggregate provide very good bond than the earlier two, are most suitable for high strength concrete and pavements; the requirement of cement paste is relatively more.

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(d) Flaky Aggregate

- These are sometimes wrongly known as *elongated* aggregate. However, both of these influence the concrete properties adversely.
- The least lateral dimension of flaky aggregate (thickness) should be less than 0.6 times the mean dimension. For example, the mean sieve size for an aggregate piece passing through 50 mm and retained on 40 mm sieve is (50 + 40)/2 = 45.0 mm and least lateral dimension is less than 0.6 × 45 = 27.0 mm, the aggregate is known as flaky.
- Elongated aggregate are those aggregate whose length is 1.8 times its mean dimension.

Note:
- Very sharp and rough aggregate particles or flaky and elongated particles requires more fine material to produce a workable concrete. Accordingly, the water requirement and, therefore, the cement content increases.
- Excellent concrete is made by using crushed stone, but the particles should be rough cubical in shape.

IMPORTANT POINTS

S.No.	Classification	Examples
1	Rounded	River or seashore gravels, desert and wind blown flints
2.	Irregular or partly rounded	Pit sands and gravels; land or dug flints
3.	Angular	Crushed rocks of types
4.	Flaky	Laminated rocks

- From the point of economy in cement requirements for a given water/cement ratio, rounded are preferred over angular aggregates.
- Where as Angular aggregates have greater durability, interlocking nature, higher surface area and higher bond characteristics, resulting in higher strengths.
- Flaky and elongated aggregates make poor concrete.

CHARACTERISTICS OF AGGREGATES

- If either the strength of the paste or bond between the paste and aggregate is low, than irrespective of the strength of aggregate, a concrete of poor quality will be obtained.
- However strength of aggregate will influence strength of concrete when the paste and bond strength are good.
- Therefore strong aggregates are an essential requirement for a strong concrete.
- Though naturally available aggregates are quite strong still they are required to be tested in certain situations like for production of high strength and ultra high strength concrete.
- Assessment of strength of aggregate is made by carrying out several tests to determine values like:
  (a) Aggregate crushing value
  (b) 10 percent fineness value
  (c) Aggregate impact value
  (d) Aggregate abrasion value

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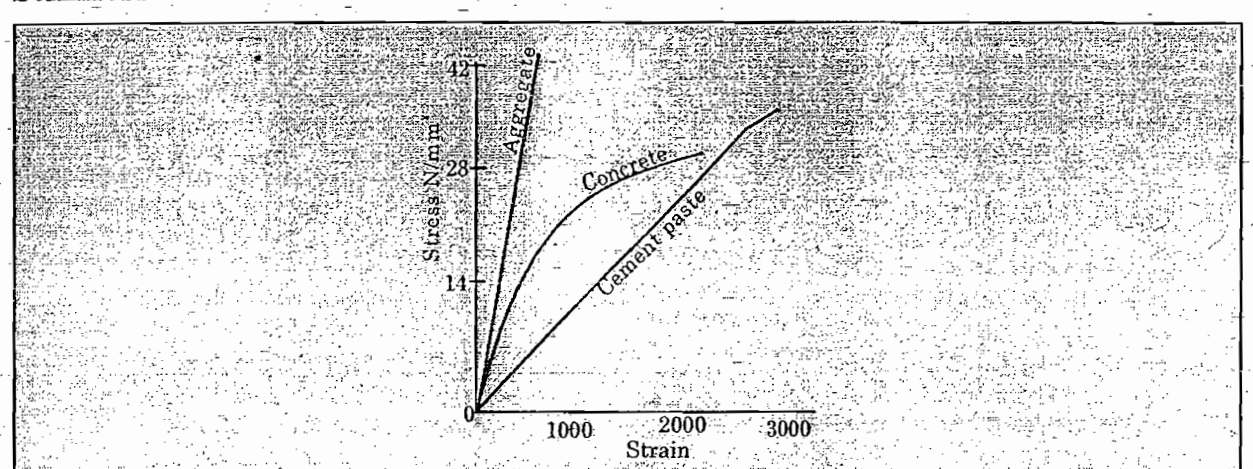
Stiffness



Stress strain Curves for Aggregate

- Modulus of elasticity of concrete is approximately equal to the weighted average of the moduli of the cement paste and the aggregate, as such the modulus of the coarse aggregate has an important influence on the stiffness of concrete.
- A high value reduces the dimensional changes due to creep and shrinkage of cement paste, but at the cost of higher internal stresses.
- Concrete that is to be subjected to wide variations of temperature and humidity, internal cracking is reduced by the use of a more compressible aggregate, but in practice this effect is rarely of sufficient importance to determine the choice of aggregate.

Bond Strength

- Difference between the coefficients of thermal expansions of paste and aggregates, and due to the shrinkage of cement paste during hardening concrete is in a state of internal stress even though no external forces are present.
- It is observed that the stresses are likely to be greatest at the paste-aggregate interfaces where minute cracks exist, even in concrete that has never been loaded.
- Under increasing external load, these cracks spread along the interfaces before extending into the paste or aggregate particles.
- Strength of the bond between aggregate and cement paste thus has an important influence on the strength of concrete.
- There is no standard test for bond but it is known that the rougher the surface texture of the particles, the better the bond.

Note: Role of particle shape is less well understood; the greater specific surface of angular particles should enable greater adhesive force to be developed, but the angular shape probably causes more severe concentrations of internal stress.

Shape and Texture

- Shape influences the properties of fresh concrete more than when it has hardened.
- Rounded aggregate and irregular are highly workable but yield low strength concrete. Same is the case with irregular shaped aggregate.
- Flaky aggregate require more cement paste, produce maximum voids and are not desirable.
- Angular shape is the best.

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- Crushed and uncrushed aggregates generally give same strength for the same cement content.
- Shape and surface texture of fine aggregate govern its void ratio and significantly affect the water requirement.

Specific Gragvity

- Specific gravity of aggregates is an important factor in design of concrete mixes as it greatly influence the strength and absorption of concrete.
- Specific gravity of aggregates generally is indirective of its quality, for most of natural aggregates it lies between 2.6 – 2.7.
- Low specific gravity indicate high porosity and therefore poor durability and low strength.
- Concrete density will greatly depend on specific gravity.

Bulk Density

- Bulk density or unit weight gives useful information regarding the shape and grading of aggregates.
- It shows how densely the aggregate is packed when filled in a standard manner.
- Higher the bulk density, the lower is the void content to be filled by the sand and cement.
- For coarse aggregate a higher bulk density is an indication of fewer voids to be filled by sand and cement.

Voids

- The void is calculated as,

$$\text{Void ratio} = 1 - \frac{\text{Bulk density}}{\text{Apparent specific gravity}}$$

- If the voids in the concrete are more the strength will be low.

Moisture Content

- Surface moisture expressed as a percentage of the weight of the saturated surface dry aggregate is known as moisture content.
- It should be noted that adsorption represents water contained in aggregate in a saturated and surface dry condition, and moisture content is the water in excess of that state, total water content of aggregate is equal to sum of absorption and moisture content.
- Coarse aggregate contains rarely more than 1 percent of surface moisture but fine aggregate can contain in excess of 10%.
- Water on the surface of aggregate will contribute to the water in the mix and will occupy a volume in excess of that of aggregate particles.
- Therefore basic state of aggregate should be saturated and surface dry.
- Therefore the presence of moisture in aggregate necessitates correction of the actual mix proportions: the mass of water added to mix has to be decreased by the mass of the free moisture in the aggregate, and the mass of the wet aggregate must be increased by a like amount.
- In case of sand (i.e. fine aggregate) there is a second effect of the presence of moisture bulking.

Bulking

- Bulking is increase in the volume of given mass of sand caused by the films of water pushing the sand particles apart.

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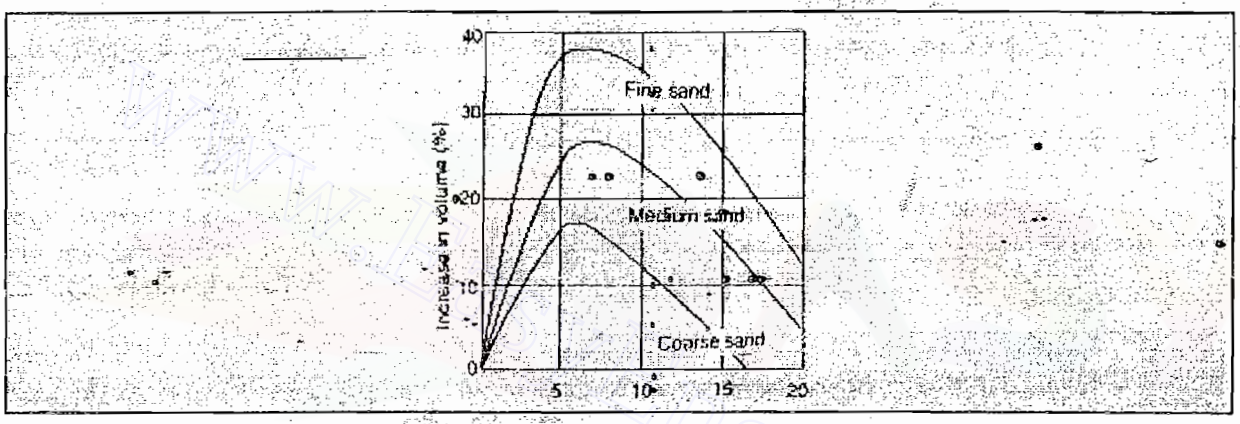
- Increase in the volume of a given mass of fine aggregate caused by the presence of water is known as bulking.
- Water forms a film over the fine aggregate particles, exerts force of surface tension and pushes them apart increasing the volume.
- Extent of bulking depends upon the percentage of moisture present in the sand and its fineness. With ordinary sand bulking varies from 15-30 percent. It increases with moisture content up to a certain point (4-6%), reaches maximum, the film of water on the sand surface breaks, and then it starts decreasing.
- In preparing concrete mixes if sand is measured by volume and no allowance is made for bulking, the moist sand will occupy considerably larger volume than that prepared by the dry sand and consequently the mix will be richer.
- In ordinary sand bulking various from 15 to 30% for increase in moisture content 5 to 8%. For fine sand this might increase to 40% also.



- In production of concrete if sand is measured by volume and no allowance is made for bulking then moist sand will occupy considerably large volume incomparision to dry volume.
- Therefore concrete produced will be rich in cement as less quantity of concrete perbag is produced.
- For example, if bulking of sand is 20% and if mix ratio is 1:2:4, and if bulking correction is not applied to sand then dry sand in the concrete will be $\frac{1}{1.2} \times 2 = 1.667$ instead of 2 per unit volume of cement.
- Mix proportion will be 1: 1.667:4 in place of 1:2:4, which indicates less production of concrete.
- To counter effect the, effect of bulking volume of sand used in the mix should be equal to $1.2 \times 2 = 2.5$ instead of 2per unit volume of cement.
- Bulking in field is determined by simple field test sample of moist sand is filled in a measuring cylinder and its volume is measured as (A).
- Now pore water and completely submerge the sand and shake and note down the volume (B).
- In above method we should have dried the sand but volume of saturated and dried sand are approximately same.
- Percentage bulking $= \frac{A-B}{B} \times 100$.

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Fineness Modulus

- Fineness modulus is defined as sum of cumulative percentage retained on the seives of the standard seives : 150 μm, 300 μm, 600 μm, 1.18 mm, 2.36mm, 4.75mm, 10mm, 12.5mm, 20mm, 63mm and 80 mm.
- It is a numerical index of fineness, giving some idea about the mean size of particles in aggregate.
- Fineness modulus (F.M) varies as 2 to 3.5 for fine aggregate 5.5 to 8.0 for coarse aggregate and 3.5 to 6.5 for all in aggregates.
- Aggregate, whose F.M. is required, is placed on a standard set of sieves and the set vibrated. Material retained on each sieve after sieving represent the fraction of aggregate coarser than the sieve in question but finer than the sieve above.
- Sum of the cumulative percentages retained on the sieves divided by 100 gives the F.M.
- Coarse aggregate have higher fineness modulus.
- Fineness modulus of 3 represents third sieve i.e. 600 μm, is the average size. Similarly F.M = 4 represents 1.18 mm as average size of aggregate.
- Purpose 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.

Deleterious Material

- Process of hydration demands aggregate to be free from impurities and deleterious substances, so as to ensure effective bond between the aggregate and the matrix.
- Substances such as organic matters, clay, shale, coal, iron pyrites, etc. which are weak, soft, fine or may have harmful physical or chemical effects on the aggregates are considered to be deleterious.
- They affect the properties of concrete in green as well as in hardened state and are undesirable.
- They are classified on the basis of interference in the process of hydration.
  1. **Impurities :** which interfere with the processes of hydration of cement; like humus or organic loam found mostly in sands.
  2. **Coating:** Which prevent the development of good bond between aggregate and the matrix; like clay, silt and other fine material.
  3. **Unsound particles:** Like iron pyrities, soft shale, clay nodules, mica, wood coal.

Soundness

- Soundness is defined as the ability of aggregate to resist changes in volume as a result of changes in physical conditions.
- The physical conditions responsible for the unsoundness are:
  (a) Freezing and Thawing
  (b) Thermal Changes at Temperature above freezing
  (c) Alternating wetting and Drying
- Porous and weak aggregates containing undesirable extraneous matter undergo excessive volume changes under favourable conditions.

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- Freeze-thaw resistance of aggregate is related to its porosity, absorption, and pore structure. This may cause local scaling to surface cracking consequently leading to impaired appearance and sometimes structural failure.

Alkali-Aggregate Reaction

- Previously aggregate were considered to be inert but later it was realised that aggregates are not fully inert.
- Infact some of the aggregates contains reactive silica, which reacts with alkalies (Na_2O and K_2O) present in the cement.
- Alkalli-Silicate gel is formed, either in planes of weakness or pores in the aggregate or on the surface of the aggregate particles.
- This gel formed is of ultimate swelling type as it imbibes water with consequent tendency to increase in volume.
- As the gel is confined by surrounding hydrated cement paste, results internal pressure and eventually lead to expansion, cracking and disruption of hydrated cement paste.

FACTORS AFFECTING ALKALI-AGGREGATE REACTION

1. Reactive type of Aggregates:

- Reactive material have been found to have serious effects if present in small quantities but not if it constitutes the whole of the aggregate.

2. High Alkali Content Cement:

- If the cement contains less than 0.4% alkalis (computed as Na_2O) no expansion or disruptive effect is likely, even with a quite highly reactive aggregate, but due to difficulties of manufacture it is not usual to specify an alkali content of less than 0.6 per cent.

3. Availability of Moisture Content:

- Alkali aggregate reaction only occurs in presence of water. That is why destructive effect is not observed in the interior mass of the concrete.

4. Temperature Condition

- Favorable temperature for the reaction is 10 to 38°C.
- At higher temperatures rate of reaction increases but does not increase the total expansion induced by reaction.

CONTROL OF ALKALI - AGGREGATE REACTION

(a) By selecting non-reactive aggregate

(b) By using low Alkali cement.

(c) By controlling moisture content.

(d) By using puzzolonas

- The aggregates are found to be reactive when they contain silica in a particular proportion and fineness. When fly-ash or surkhi or crushed stone dust is added this optimum condition of silica being in particular proportion and fineness is disturbed and the aggregates turn to be innocuous.

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(e) By air entraining agents

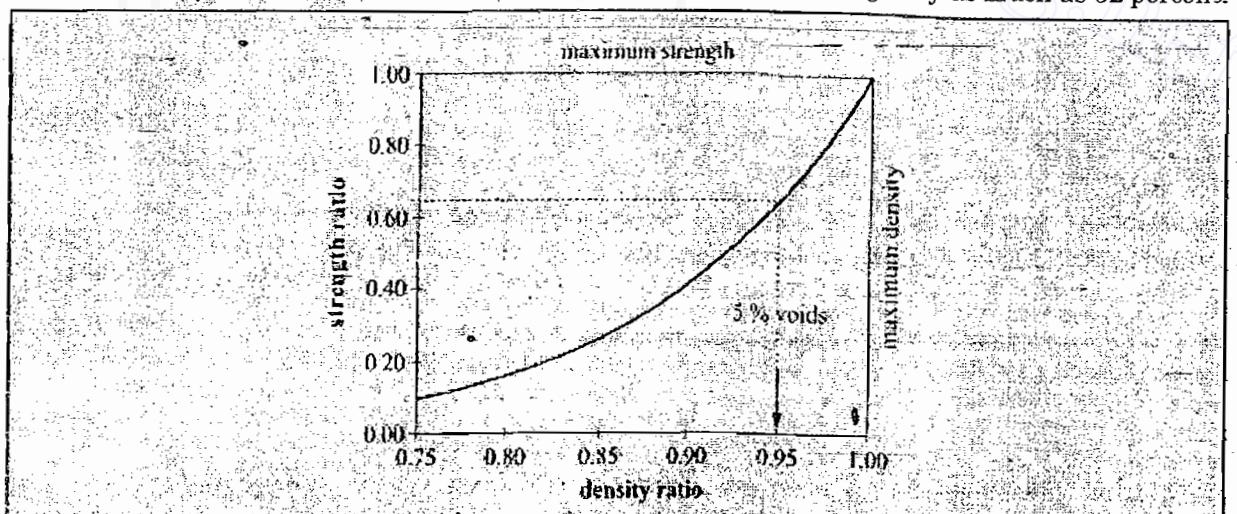
- Alkali-silica-gel imparts osmotic pressure over the set cement gel and this is mainly responsible for formation of cracks. When air entraining agents are added they absorb the osmotic pressure and control the expansion.

Thermal Properties

- Thermal properties of aggregates which are significant for establishing the quality of aggregate for use in concrete are:
  (a) Coefficient of expansion
  (b) Specific heat
  (c) Thermal conductivity.
- Coefficient of expansion is importance to us for our day to day concreting work, as it interacts with coefficient of thermal expansion of concrete paste. The other two thermal properties are of significance only in mass construction or light weight concrete.
- Coefficient of thermal expansion of concrete increases with that of coarse aggregate. Any appreciable difference in the coefficients of coarse aggregate and cement paste may break the bond between the two. Freezing and thawing effect may be prominent if the difference in the two is more than 5.4 × 10-6 per °C.

GRADING REQUIREMENTS OF AGGREGATE

- 'Grading' is the particle size distribution of aggregate; it is measured by sieve analysis [IS 2386 (Part 1); 1963], and is generally described by means of a grading curve, which shows the cumulative percentage passing' against the standard IS sieve sizes.
- The grading (as well as the type and size) of aggregate is a major factor which influences the workability of fresh concrete, and its consequent degree of compaction.
- It is of extreme importance with regard to the quality of hardended concrete, because incomplete compaction results in voids, thereby lowering the density of the concrete and preventing it from attaining its full compressive strength capability also the impermeability and durability characteristics get adversely affected.
- It is observed that as little as 5 percent of voids can lower the strength by as much as 32 percent.



Relation between density ratio and strength ratio

I.E.S MASTER
Institute for Engineers
IES/GATE/PSUs
Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
Phone: 011-41013406, 7838813406, 9711853905

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- From an economic viewpoint, it is desired to aim for maximum density by a proper grading of aggregate alone — with the smaller particles fitting, as much as possible, into the voids of the larger particles in the dry state, thereby limiting the use of the (more expensive) cement paste to filling in the voids in the fine aggregate.
- Unfortunately, such a concrete mix is prone bo be 'harsh' and unworkable. Moreover, it is very likely to segregate, with the coarser particles separating out or settling more than the finer particles.
- The cement paste must be in sufficient quantity to be able to coat properly all the aggregate surfaces, to achieve the required workability, and to ensure that the particle sizes are distributed as homogeneously as possible without segregation.
- Pressure of more 'fines' (sand and cement) in a mix is found to improve both workability and resistance to segregation, because the fines thend to 'lubricate' the larger particles, and also fill into their voids as mortar.
- But too much of fine aggregate in a mix is considered to be undesirable, because the durability and impermeability of the hardened concrete may be adversely affected.

CONVENTIONAL QUESTIONS

1. List the principal requirements of aggregate for concrete. Defind "fineness modulus" of an aggregate and explain its significance. **(1992)**
2. Explain the phenomenon of BULKING of sand and its significane. How is it determined? **(1996)**
3. Explain how bulking of fine aggregate takes place and how it is taken care of in the field. Also explain the method of preparation of bulking chart in the laboratory. **(2006)**

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OBJECTIVE QUESTIONS

1. If in a concrete mix the fineness modulus of coarse aggregate is 7.6, the fineness modulus of fine aggregate is 2.8 and the economical value of the fineness modulus of combined aggregate is 6.4, then the proportion of fine aggregate is

(a) 25% (b) $33\frac{1}{3}\%$

(c) 50% (d) $66\frac{2}{3}\%$

2. Which one of the following statements is correct?

(a) Bulking of sand always decreases with increase in the quantity of water.

(b) The quantity of water in ordinary concrete should be 5% by weight of cement and 25% by weight of aggregate.

(c) While mixing by weight, bulking effect of sand is not taken into account.

(d) River sand is also known as standard sand.

3. Match List-I (Property) with List-II (Characdteristic) and select the correct answer using the codes given below the lists:

List-I

A. Specific heat of an aggregate

B. Thermal conductivity of an aggregate

C. Thermal expansion

D. Durability of concrete

List-II

1. Breaks the bond between the aggregate and the paste

2. Is a measure of its heat capacity

3. Is affected by differences in thermal expansion of two different materials

4. Is a measure of its ability to conduct heat

Codes

	A	B	C	D
(a)	1	3	2	4
(b)	2	4	1	3
(c)	1	4	2	3
(d)	2	3	1	4

4. What is the range of fineness modulus of sand which is least suitable for making a good concrete?

(a) 3.5 - 4.5 (b) 2.9 - 3.2

(c) 2.6 - 2.9 (d) 2.2 - 2.6

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5. Which of the following pairs are correctly matched?

1.	Particle size and texture	: Affects workability
2.	Absorption and surface moisture	: Affects mix proportions
3.	Grading	: Maximizes cement content
4.	Bulk density	: Significant for stability

Select the correct answer using the codes given below:

(a) 1 and 2 (b) 2 and 3

(c) 3 and 4 (d) 1 and 3

6. What is the percentage of the fine aggregate of fineness modulus 2.6 to be combined with coarse aggfregate of fineness modulus 6.8 for obtaining combined aggregate of fineness modulus 5.4?

(a) 30% (b) 40%

(c) 50% (d) 60%

7. Which factors influence the workability of concrete without sacrificing strength?

1. Fine aggregate
2. Quantity of mixing water
3. Maximum size of coarse aggregate
4. Shape of coarse aggregate

Select the correct answer using the codes given below:

(a) 1 only (b) 2 only

(c) 1 and 2 (d) 3 and 4

8. What is the representative geometric mean size of an aggregate sample if its fineness modulus is 3.0?

(a) 150 mm (b) 300 mm

(c) 600 mm (d) 12 mm

9. Which one of the following statements is correct?

(a) Adding 5% to 6% of moisture by weight increases the volume of dry sand from 18% to 38%.

(b) The bulking of fine sand is more than that of coarse sand.

(c) Volume of full saturated sand is equal to that of dry sand.

(d) All of the above

10. Which one of the following aggregates gives maximum strength in concrete?

(a) Rounded aggregate (b) Elongated aggregate

(c) Flaky aggregate (d) Cubical aggregate

11. Match **List-I** (Aggregate) with **List-II** (Effect) and select the correct answer using the codes given below the lists:

List-I

A. Rounded aggregates

B. Crushed aggregates

C. Flaky aggregates

D. Irregular aggregates

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List-II

1. Reduce workability appreciably because of a high ratio of surface area to volume
2. Require more water than rounded aggregates and give strength lesser than crushed aggregates
3. Give concrete of higher compressive strength due to development of stronger aggregate-mortar bond
4. Require lesser amount of water and cement paste for a given workability

Codes

	A	B	C	D
(a)	1	2	4	3
(b)	1	3	4	2
(c)	4	3	1	2
(d)	4	2	1	3

12. The fineness modulus of the aggregate is 2.78 and of coarse aggregate is 7.82 and the desired fineness modulus of mixed aggregate is 6.14. What is the amount of fine aggregate to be mixed with one part of coarse aggregate?

(a) 55% (b) 50%
(c) 45% (d) 40%

13. In a shape test of aggregate, Which one of the following gives the correct slot for flakiness index for a material pasing 50 mm sieve and retained on 40 mm sieve?

(a) 25 mm (b) 27 mm
(c) 81 mm (d) 30 mm

14. **Assertion (A) :** Addition of 5% to 6% of moisture content by weight increases the volume of dry sand from 18% to 38%.

Reason (R) : Bulking of sand is caused due to surface moisture on sand particles.

15. **Assertion (A) :** The specific surface of aggregate decreases with increase in size of the aggregate.

Reason (R) : Air entraining agent increases concrete strength.

ANSWERS

1.	(b)	5.	(a)	9.	(d)	13.	(b)
2.	(c)	6.	(c)	10.	(d)	14.	(a)
3.	(b)	7.	(d)	11.	(c)	15.	(b)
4.	(a)	8.	(c)	12.	(b)		

I.E.S MASTER
Institute for Engineers
IES/GATE/PSUs
Office: F-126, Katwaria Sarai, New Delhi - 110 016
Website: www.iesmaster.org, E-mail: ies_master@yahoo.co.in
Phone: 011-41013406, 7838813406, 9711853908

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CHAPTER

7

Water

INTRODUCTION

- Water is most important ingredient for production of concrete and least expensive one also.
- Purpose of using water is to cause hydration of the cement.
- Quantity of water is to be carefully controlled during manufactured of concrete.
- Water in excess of that required for hydration acts as a
  - (a) Lubricant between coarse and fine aggregates and produces a workable and economical concrete.
  - (b) The cement along with water comes to the surface by capillary action and forms a thin layer over surface known as laitance. This weakens bond between the successive lifts of concrete.
  - (c) The excess water may leak through the form work, resulting in honeycombed concrete and on evaporation makes the concrete porous.
- Where as lesser water makes concrete difficult to work with concrete and due to nonuniform mixing the resultant concrete is weaker in strength.
- Water is also used for washing aggregates and curing.

QUALITY OF WATER

- In civil engineering industry it is a perception that any natural potable water that has no pronounced taste or odour is acceptable for the concrete.
- But above statement does not appear to be a true for all conditions.
- Some waters containing a small amount of sugar would be suitable for drinking but not for mixing concrete and conversely water suitable for making concrete may not necessarily be fit for drinking.
- In case of a doubt, water samples should be tested for suitability.
- Excessive impurities may affect setting time, strength, durability and may cause efflorescence, surface discoloration, and corrosion of steel.
- Effects of impurities in water are mainly expressed in terms of setting time of Portland cement.
- Initial setting time of the mixes with impure water and that with the pure water are obtained. Their difference in the initial setting time of ± 30 minutes with initial setting time not less than 30 minutes is supposed to be acceptable.
- 7 day and 28 day compressive strengths of the cube/cylinder specimens prepared with impure water should not differ by 10 per cent from that of cubes/cylinders prepared with pure water.

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Tolerance Concentration of impurities in Mixing Water		
S.No.	Impurity	Tolerable Concentration
1.	Silt and suspended particles	2,000 ppm
2. (i)	Carbonates and bicarbonates of Na or K	1,000 ppm
(ii)	Bicarbonates of Mg	400 ppm
3.	Chlorides	10,000 ppm
4.	Sulphates	20,000 ppm
5.	Sulphuric anhydride	3,000 ppm
6.	Calcium chloride	2% by weight of cement
7.	Sodium sulphide	<100 ppm
8.	Sodium hydroxide	0.5% by weight of cement
9.	Dissolved salts	15,000 ppm
10.	Organic matter	3,000 ppm
11.	pH	6-8
12.	Iron salts	40,000 ppm
13.	Acids (HCl, H_2SO_4)	10,000 ppm
14.	Sugar	500 ppm

Suspended Particles

- Water containing less than 2000 ppm (parts per million) of dissolved solids can generally be used satisfactorily for making concrete.
- Even higher percentage can be tolerated so far as strength is concerned, but other properties of concrete like setting and hardening properties bond characteristics are considerably affected.
- Mixing water with a high content of suspended solids should be allowed to stand in a setting basin for sufficient period before it is used for concrete making.

Inorganic Salts

- Presence of salts of manganese,tin, zinc, copper and lead in water causes reduction in the strength of concrete.
- Zinc chlorides retard the set of concrete to such an extent that no strength tests are possible at 2 and 3 days.
- Effect of lead nitrate is completely destructive.
- Sodium iodate, sodium phosphate, sodium arsenate and sodium borate reduce the initial strength of concrete to an extraordinarily high degree.
- While sodium carbonate may cause quick setting, the bi-carbonates may either accelerate or retard the setting. Higher concentrations of these salts will materially reduce the concrete strength. If some of these salt exceeds 1000 ppm tests for setting time and 28 days strength should be carried out.
- Brackish water ~~and the sea~~ water generally contains 3.5 percent of dissolved salts, about 78 percent of which is sodium chloride and 15 percent chloride and sulphate of magnesium. These salts percent in sea water reduce the ultimate strength of concrete. May be of the order of 10 to 20 percent.

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- The major concern is the risk of corrosion of reinforcing steel due to chlorides.
- Sodium sulphide is detrimental to concrete and even a sulphide content of 100 ppm needs testing.
- Calcium chloride accelerates setting and hardening of cement.

Acid and Alkalies

- Water containing acids or alkalis (industrial waste water) is supposed to be unsuitable for making concrete.
- Water with pH value between 6-8 should only be used.
- However, the pH value alone may not be satisfactory measure of the amount of acid.
- It is the total acidity which should be measured.
- This can be measured by titrating 100 ml of sample of water with 0.1 normal NaOH using phenolphthalein as indicator.
- Amount of such 0.1 N_2 NaOH solution to neutralize 100 ml sample of water should not be more than 1 ml. This acidity is equivalent to 49 ppm of H_2SO_4 or 36 ppm of HCl.
- The limit of alkalinity is guided by the requirement that the amount of 0.1 N HCl required to neutralize 100 ml of sample should be less than 5 ml. This alkalinity is equivalent to 265 and 420 ppm of carbonates and bicarbonates, respectively.

Sugar

- When the amount of sugar present in the mixing water is less than 0.05 percent by weight of water there is no adverse effect on the strength of concrete.
- If small amounts of sugar upto 0.15 percent by weight of cement retard the setting of cement and the early strengths may be reduced whereas the 28-day strength may be improved.
- If the quantity of sugar is increased to 0.20 percent by weight of cement, setting is accelerated.
- If the quantity is further increased, rapid setting may result and 28-day strength reduced.

Oil Contamination

- Mineral oils not mixed with animal or vegetable oils in mixing water have no adverse effect on the strength of concrete.
- If the concentration of mineral oils is upto 2 percent by weight of cement, a significant increase in strength has been noticed. For a percentage of mineral oils more than 8 percent, the strength is slightly reduced.
- Vegetable oils have detriments effect on water.

Algal

- Algae, present in mixing water or on the surface of aggregate either reduces bond by combining with the cement or reduces strength by entraining a large amount of air in the concrete.

EFFECT OF MIXING WATER FROM DIFFERENT SOURCES

Ground Water

- Ground waters rarely contain more than 20 to 30 ppm of iron. But, acid mine waters may carry rather large quantities of iron.

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- Iron salts in concentrations up to 40,000 ppm do not usually affect mortar strengths adversely.

Sea Water

- Curing sea water can be used in case of plain and reinforced concrete both as mixing water as also as water but mix proportion to be altered to make concrete dense (using rather high cement content and adopting low W/C ratio) and adequate cover to be provided on reinforcement.
- But since these factors cannot be adequately taken care always at the side, it may be wise that sea water be avoided for making reinforced concrete.
- Use of sea water must be avoided under any circumstances in prestress concrete work because of steel corrosion and undue loss of cross-section of small diameter wires.
- Sea water slightly accelerates the setting time of cement. It also slightly accelerates the early strength of concrete. But it reduces 28 days strength of concrete by about 10 to 15 percent.
- But this loss of strength could be made up by redesigning the mix.
- Salts in sea water may cause efflorescence and persistent dampness.
- When the appearance of concrete is important sea water may be avoided.
- Use of sea water is also not advisable for plastering purposes which is subsequently going to be painted.

Industrial Waste Water

- Generally Industrial waste water have less than 3000 ppm of total solids.
- When such water is used as mixing water in concrete, the reduction in compressive strength is generally less than about 10 per cent.
- Waste waters from paint factories, coke plants, chemical and galvanizing plants may contain harmful impurities.
- A one way of using sewage containing large organic matters (say 400 ppm) is to dilute it in a good disposal system to reduce the concentration to about 20 ppm or less, an amount too low to have any significant effect on concrete strength.

Water for Washing Aggregates

- Aggregates washed with water containing impurities, get coated with layers of silt, salts and organic matters.
- This reduce the bond between the aggregates and cement and markedly affect the strength.

Curing Water

- Water fit for making concrete can be used for curing.
- Waters containing impurities and leading to stains is objectionable.
- It concrete is subjected to prolonged wetting, even a very low concentration of iron and organic matter may cause staining. Water containing more than 0.08 ppm of iron is not recommended for curing.

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