BYJU'S EXAM PREP

GATE/ESE

Civil Engineering

Building Materials

Important Formula Notes

IMPORTANT FORMULAS ON BUILDING MATERIALS

CHAPTER-1-CEMENT

INTRODUCTION

- Cement is material having adhesive and cohesive properties in presence of water which provide a binding medium for the discrete ingredients.
- Standard bulk density of cement is 1440kg/m^3 & Sp. Gravity is 3.15
- Volume of cement of 1 bag of 50kg is 35 litres.

MANUFACTURING OF CEMENT:

- Raw materials required for manufacture of Portland cement are calcareous and argillaceous material. Calcareous Material-Compounds of calcium such as limestone or chalk Argillaceous Material-Compounds of Silica, Alumina & oxides of iron such as clay and shale.
- Process consists of grinding the raw materials, mixing them in certain proportions depending upon their purity and composition and burning them in a kiln at 1300 to 1500 C.
- At this temperature, material sinters and fuses to form what is called as clinker (a solid solution)
- Clinker is cooled & grounded to fine powder, while grinding Gypsum (3-5%) is added in order to prevent flash-setting of the cement, this results in formation of OPC.
- There are two processes known as "wet" and "dry" processes depending upon whether the mixing and grinding of raw materials is done in wet or dry conditions
- Previously wet process was used because control in the mixing of raw materials in powder form was not available then.
- Today dry process is used because as technique of dry mixing of powdered materials is available and it is more energy efficient (requires much less fuel).
- In dry process as materials are already in a dry state, whereas in wet process material are in slurry form having 35% to 50% of water.
- To dry the slurry we require more fuel.

CHEMICAL COMPOSITION OF RAW MATERIAL:

- Three basic constituents of hydraulic cement are lime, silica and alumina.
- Relative composition and their respective functions are listed below.

Ingredient	Function	%	Av. %
Lime (Cao)	• It controls strength and soundness. • Its deficiency reduces strength and setting action(time required to change from plastic to solid	60-65	62

	state of paste) and excess of it cause unsoundness (cement to expand and disintegrate).		
Silica (SiO_2)	• It imparts strength. • Excess of it increase the strength but setting action is prolonged.	17-25	22
Alumina (Al_2O_3)	• Responsible for quick setting. • Strength decreases as alumina in excess amount.	3-8	5
Calcium sulphate ($CaSO_4$)	• It increases initial setting time (time period during paste remains in plastic state) of cement.	3-4	4
Iron oxide (Fe_2O_3)	• Gives colour and helps in fusion of different ingredients. • Excess of it produce a hard clinker which is difficult to grind.	0.5-6	3
Magnesia (MgO)	• it imparts colour and hardness (rigidity of paste) • Excess of it makes cement unsound.	0.5-4	2
Sulphur trioxide (SO_3)	• Excess of it makes cement unsound	1-3	1
Alkalies {Soda and potash}	• These are residue. • Excess of it cause efflorescence and cracking	0.5-1.3	1

BOGUE'S COMPOUNDS

- Raw material when subjected to high clinkering temperature combines with each other to form complex compounds known as **Bogue's Compounds**.
- Bogues compounds are formed during clinkering process.
- Properties of Portland cement varies significantly with the proportions of these four compounds, as substantial difference is observed in their individual behaviour.

Bogue's compound	**Functions**
Tri Calcium Silicate (C_3S) 25 to 50% normally 40% $3CaO.SiO_2$ **Alite**	• Best cementing material among all four Bogues Compounds. • Helps clinkers easy to grind. • Increase resistance to freezing and thawing (melting) • It hydrates rapidly generating high heat and develops an early hardness and strength (mainly 7 Days). • Raising of C_3S content beyond the specified limits increases heat of hydration and solubility of cement in water, but free lime will be more and cement will be unsound. Main cause of hardness and Party strength of cement paste

	• Heat of hydration is 500 J/gm
Di Calcium Silicate (C_2S) 25 to 40% normally 32% $2CaO.SiO_2$ **Belite**	• It hydrates and harden slowly (>1 year or more) hence responsible for ultimate strength. • helps resistance to chemical attack. • raising of C_2S content result in harder to grind clinker, reduces early strength and decrease resistance to freezing and throwing at early ages and decreases heat of hydration. • At early ages (<1 month) C_2S has little influence on strength and hardness but after one year it is almost equal to C_3S. • Heat of hydration is 260 J/gm.
TriCalcium Aluminate (C_3A) 8 to 12% normally 10% $3CaO.Al_2O_3$ **Celite**	• rapidly reacts with water and responsible for flash set (stiffening without strength development). • rapidity of action is controlled by addition of 2 to 3% of gypsum (calcium sulphate) at the time of grinding of cement. • most responsible for initial setting, high heat of hydration and has greatest tendency to volume change causing cracking. • Raising of C_3A contents reduces the setting time, resistance to sulphate attack declines and lowers the ultimate strength • Heat of hydration is 865 J/gm.
Tetra calcium alumina ferrite (C_4AF) 6 to 10% normally 8% $4CaO.Al_2O_3.Fe_2O_3$	• it is responsible for flash set but generates less heat. • it has poor cementing value because hydrated product due to C_4AF also does not contribute anything to strength • if C_4AF is increased it slightly reduces the strength • heat of hydration is 420 J/gm. • It is also called Felite.

HYDRATION OF CEMENT

- Chemical reaction between cement and water is known as hydration of cement. it is an exothermic reaction.
- This setting (the change of cement paste from plastic to stiff solid state) and hardening (gain of strength with hydration) is a chemical reaction, wherein water plays an important role and it's not just a matter of drying out, in fact setting and hardening stops as soon as the concrete becomes dry.
- C_3S produces less C-S-H gel and more $Ca(OH)_2$ as compared to C_2S.
- $Ca(OH)_2$ is not 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 smaller percentage of C_3S and more C_2S is recommended for using in hydraulic structures.

- Alternative way to overcome this difficulty is to grind some pozzolanic material (fly ash combined with lime)with cement. pozzolana is a siliceous material which reacts with lime in presence of moisture to give a relatively strength producing calcium silicate.
- the only advantage of $Ca(OH)_2$is that being alkaline in nature it maintains pH of 13 in concrete which resist the corrosion of reinforcement.
- Rate of hydration of the bogue's compounds will be in following descending order
  $C_4AF > C_3A > C_3S > C_2S$
- Heat of hydration both books combined will be in following descending order
  $C_3A > C_3S > C_4AF > C_2S$
- Higher is the temperature rapid is the hydration, hence in cold weather aggregates are heated before they are used for making concrete. Hydration of concrete ceases at -11°C.
- Finer is the cement rapid will be the hydration, because finer cement has larger surface area. Although total heat evolved will be same both in case of fine cement or coarser cement. However, a very fine ground cement is susceptible to air set and deteriorates early.
- **Water requirement for hydration:** About an average 23% (24% for C_3S and 21% for C_2S) water by weight of cement is required for complete hydration of Portland cement. It is further observed that 15% of water by weight of cement is required to fill the gel pores. A total of 38% of water by weight of cement is required to complete the chemical reaction and to occupy the space within the gel pores.
- **Flash setting of cement:** flash setting is defined as immediate stiffening of Portland cement paste, mortar or concrete. It is due to very fast reaction of C_3A with water. This rigidity cannot be overcome and also plasticity cannot be regained by further mixing without addition of water. causes of flash setting are (i) presence of high tricalcium aluminate (ii) less gypsum added to the cement and (iii) presence of alkalis.
- **false set:** Rapid stiffening or hardening in freshly mixed Portland cement concrete motor or concrete (with no appreciable evolution of heat). Plasticity of paste can be regained by only remixing of cement paste without addition of water. Reason for false set are (i) grinding too hot clinkers with gypsum dihydrate and formation of gypsum Semi-hydrate (ii) low C_3A + high gypsum will result in false set (iii) some concrete admixtures such as lignin sulfonate (water reducer) negatively affect the solubility of gypsum and increases the tendency towards false set (iv) alkalis in the cement.

FIELD TESTS FOR CEMENT

- **Colour:** Grey colour with a light greenish shade.
- **Physical Properties:** Cement should feel smooth when touched between fingers.
- If a hand is inserted in a bag or heap of cement, it should feel cool.
- If a small quantity of cement is thrown in a bucket of water, it should float for some time before sinking.
- A thin paste between fingers should feel sticky.
- **Presence of lumps:** Cement should be free from lumps.

LABORATORY TESTS FOR CEMENT

1. Chemical Composition Test

- Ratio of percentage of lime to percentage of silica, alumina and iron oxide known as Lime Saturation Factor (LSF), when calculated by the formula shall not be greater than 1.02 and not less than 0.66.

$$\frac{CaO - 07SO_3}{(28SiO_2 + 12Al_2O_3 + 0.65Fe_2O_3)}$$

- Ratio of percentage of alumina (Al_2O_3) to that of iron oxide (Fe_2O_3) shall not be less than 0.66
- Weight of insoluble residue shall not be more than 4 per cent.
- Weight of Magnesia Shall not be more than 6 per cent
- Total loss on ignition shall not be more than 5 per cent.
- Total sulphur content calculated as sulphuric anhydride shall not be more than 2.5% when C_3A is 5% or less and shall not be more than 3% when C_3A is more than 5%

2. Normal Consistency Test

- The normal (standard) consistency of a cement paste is defined as that consistency which will permit a Vicat plunger having 10 mm diameter and 50 mm length to penetrate a depth of 33 to 35 mm from the top (or 5 to 7 mm from the bottom) of the mould.
- **Vicat Apparatus:** Vicat apparatus assembly consists of a plunger 300 gm in weight with a length of 50 mm and diameter of 10 mm and a mould which is 40 mm deep and 80 mm in diameter.

3. Initial Setting Time Test

When water is added to cement, the resulting paste starts to stiffen and gain strength and loose the consistency simultaneously. The term setting implies solidification of the plastic cement paste. Initial and final setting times may be regarded as the two stiffening states of the cement. The beginning of solidification, called the initial set, marks the point in time when the paste has become unworkable

- Initial setting time should not be less than 30 minutes for OPC and 60 minutes for low heat cement.
- A cement paste is prepared by gauging cement with 0.85 times the water required to prepare a paste of standard consistency.
- In vicat's apparatus a square needle of area 1 mm^2 is used and when the penetration is not more than 33 to 35 mm from the top it is assumed that initial setting has started.

4. Final Setting Time Test

- The cement paste is prepared same as the initial setting time test, here the needle with 5mm diameter annual collar is attached in place of 1$mm^2$for determination of final setting time.
- if the needle makes an impression not more than point 0.5mm but the edge of the collar fails to do so the paste is assumed to be finally set.
- The final setting time should not be more than 10 hours.

5. Soundness Test

- The purpose of soundness test is to determine change in volume of cement after setting.
- Unsoundness of cement is due to the presence of free lime and magnesia which slake slowly causing change in volume of cement. Therefore, freshly grinded cement is allowed to aerate for two to three weeks allowing the lime to hydrate and overcome unsoundness. sometimes excess gypsum added to cement to retard the setting time can cause unsoundness by formation of calcium-sulpho-eliminate hence very strict control is kept over quantity of gypsum added to clinker.
- unsound cement causes cracks distortion and disintegration (due to expansion), ultimately leading to failure of the structure.
- Le Chatelier's Methodcan only indicate unsold next due to free line it does not indicate presents and after effect of excess of magnesium.
- Le Chatelier's method 100 grams cement is mixed with 0.78 times the water required to give a paste of standard consistency.
- Autoclave Testheat sensitive to both free lime and magnesia.

6. Strength Test

(a) Compressive Strength Test

- For compressive strength test 200 grams of cement is mixed with 600 grams standard sand (Ennore sand) and (P/4+3)% off water is added until the mixture is of uniform color. where P is the percentage of water required to produce a paste of normal consistency.
- Three cubes having size 70.6 mm or face area of 5000$mm^2$are tested for compressive strength, at 1 day, 3 day, 7 days and 28 day where the period of testing is reckoned from the completion of vibration.
- Load is applied starting from zero at a rate of 35 N/mm^2/min. The compressive strength shall be the average of the strengths of the three cubes for each period respectively.

(b) Tensile Strength Test

- Motor is prepared by 1:3 (cement: sand) by weight, water is to be used is (P/5+2.5)% where P is the standard consistency of cement.
- Six briquettes are tested, and average tensile strength is calculated.
- A load is applied steadily and uniformly, starting from zero and increasing at the rate of 0.7 N/mm^2 in 12 seconds.
- Strength increases when the loading rate is increased from the specified rate.
- OPC should have a tensile strength of not less than 2 MPa after 3 days and 2.5 MPa after 7 days respectively.
- Generally, tensile strength is 10-15% of compressive strength.

7. Fineness Test:

- Fineness of cement is measure of mean size of grains i.e. the degree to which it is grinded. Finner is the cement more is the surface area of a given volume of cement higher will be the rate of hydration because more surface area is available for cement water reaction.

- Cement become finer with age.
- Setting time of the cement decreases as the fineness of the cement increases.
- Rate of gain of strength is higher but ultimate strength is not affected.
- Fine cement bleeds less than the course cement because more surface area is available for water to be attached.
- Finer cement leads to a stronger reaction with alkali reactive aggregates and increases the chances to shrinkage and cracking of cement paste.
- Fineness of cement is expressed as cm^2/gm.

There are three methods for testing fineness viz.

(a) Sieve Method

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

	Type of cement	% Residue by weight
(i)	Ordinary Portland cement	10
(ii)	Rapid hardening cement	5
(iii)	Portland Pozzolana cement	5

(b) Air Permeability Method

(c) Wagner Turbidimeter Test

8. Heat of hydration Test

- The apparatus used to determine the heat of hydration of cement is known as **calorimeter**.
- The heat of hydration for low heat Portland cement should not be more than 66 and 75 cal/gm for 7 and 28 days respectively.

9. Specific Gravity Test

- The specific gravity of cement is obtained by using **Le Chatelier's flask**.
- Generally specific gravity of OPC is equal to 3.15.
- cement with higher content of iron oxides have higher specific gravity.

10. Loss on ignition

- 1 gm of cement is heated for 15 min in a weighed and covered platinum Crucible of 20 to 25 ml capacity by placing it in a muffle furnace at any temp between 900-1000 degree Celsius.
- The percentage loss on ignition should not be more than 4%.

TYPES OF CEMENT

1. Ordinary Portland cement

- Higher is the strength of Portland cement higher will be the rate of heat development during hydration of cement.
- OPC can be classified in three grades: 33 grade 43grade53 grade. where 33, 43, 53 are characteristic strength of cement at 28 days.

2. Rapid Hardening Cement (IS: 8041)

- This cement is obtained from OPC but grinded more.
- More C_3S (up to 50%) and less C_2S.
- 1 day strength of RHC 3-day strength of OPC with the same W/C ratio.
- 3-day strength of RHC 7-day strength of OPC with the same W/C ratio.
- Used in situations where a rapist development of strength is desired (Ex 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 inside temperature in concrete increases and causes cracking.
- Large shrinkage and water requirement for workability is more Concrete made with RHC can be safely exposed to frost as a matures more quickly.
- Cost of rapid hardening cement is about 10% more than the ordinary cement.

3. High alumina cement (IS:6452)

- Raw material used are 40% bauxite, 40% lime, 15% iron oxide with little % of ferric oxide, silica and magnesia etc by fusing at very high temperature 1550-1500°c)
- As the heat required for the manufacture of this cement is more the manufacturing cost of this cement is high
- Allows more time for mixing and placing operation.
- Since C_3A is not present the cement is good resistance against attack by sulphate.
- it evolves great heat during setting It is therefore not affected by frost but cannot be used in mass concreting works
- Due the property of rapid hardening (high heat of hydration), high early strength and good chemical attack resistance, widely used in marine construction & sewer infrastructure.
- It has high resistance against fire, used in refractory concrete where it requires more strength at very high temp.

4. Portland slag cement (IS:455)

- It is obtained by grinding OPC clinker, granulated blast furnace slag (25-65%) and gypsum. Slag is waste product in manufacture of pig iron which contains silica around 25-40% and lime 35-50%.
- Fineness, setting time, soundness and strength are same as that for 33 grade OPC
- Low heat of hydration hence can be used for mass concrete.
- Bate of hardening an OPC during the first 28 days but there after increases and close to 12 months strength becomes equal to or more than OPC.
- They have lower lime high silica and alumina
- Better resistance to chemical attack (especially chlorides & sulphates), hence can be used for Marine Works and Sewer Works.

5. sulphate resistant Portland cement (IS: 12330)

- It is similar to OPC except that it contains very low C_3A content (<5%), ground finer than OPC and high silicate content

- 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.
- It can be used in Structures in sea water, coastal area, marshy lands, sewage and canal linings
- **Note**: OPC subjected to sulphate attack specially $MgSO_4$, Sulphates react with free calcium hydroxide to form calcium sulphate and hydrate of calcium aluminate to form calcium sulpho aluminate volume of which is approximately 227% of the volume of the original volume causes cracks in cement paste and concrete due to expansion.

6. 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.
- Rate of development of strength is slow but ultimate strength is same as that of OPC
- Low heat evolved, preventing shrinkage at high temperature. Used for mass concreting of dam and bridges etc.

7. Quick setting cement

- In the manufacturing of this cement gypsum content is reduced who get the quick setting property, also small amount of alumina sulphate.
- It is grounded much finer than OPC.
- it sets quickly but does not harden quickly.
- initial setting time is 5 minutes and final setting time is around 30 minutes.
- it is used for concreting under water or in running water.

8. White and colored Portland cement

- Manufactured from pure white chalk and clay free from iron oxide.
- Gray color of cement is due to iron oxide, so for white cement iron oxide should be less than 1%. colored cements are made by adding 5 to 10% coloring pigments before grinding.
- Compressive strength of this cement is 10% of that 33 grade of OPC.
- hunter scale or ISI scale is used to measure the whiteness of white cement.

9. Expensive cement

- this cement does not shrink or suffer any overall change in volume on drying while hardening and thereafter expand slightly with time.
- Commonly used for grouting anchor bolts or grouting machine foundation or prestressed concrete ducts where in drying shrinkage may otherwise defeat the purpose of grouting.
- expensive cement is obtained by mixing 8 to 20 parts of sulpho -aluminate clinkers with 100 parts of OPC and 15 parts of stabilizer.

10. Hydrophobic cement or water repellent cement

- stearic acid, boric acid, oleic acid and pentachlorophenol are added to OPC (0.1%-0.5% of weight of cement) during grinding of cement clinker. These acids form a film around the cement particles which prevent the entry of atmospheric moisture and this film breaks down when the concrete is mixed and then the normal hydration take place.
- Note: hydrophobic cement has small strength gain initially because of the hydrophobic films on cement grains which prevent the interaction with water but it's 28 day strength is equal to OPC.

11. Air entraining cement

- It is manufactured by adding small amount off air entraining agent with OPC clinker at the time of grinding. This improves workability and water-cement ratio can be reduced which reduces shrinkage.
- Also minute voids increases resistance against freezing and scaling action of salts.
- Air entraining cements are used for the same purpose as that of OPC but it has higher initial setting time and longer final setting time than OPC.
- Various air entraining agents are aluminum powder, zinc powder, hydrogen peroxide, natural wood resigns and calcium ligno-sulphates.

12. Portland pozzolana cement

- It is manufactured by grinding Portland cement clinker and pozzolana (15 to 35%) or by uniformly blending OPC and with fine pozzolana.
- Pozzolana's a siliceous and aluminous material which has no cementing property itself but has the property of combining with lime to produce a stable compound which has definite cementitious property.
- Pozzolana can be Fly ash, blast furnace slag, rice husk etc. calcium hydroxide.
- Pozzolanic action is very slow hence it has low heat of hydration and low rate of gain of strength, but ultimate strength is comparable to OPC.
- as low heat is involved so it can be used for mass concreting such as dams, it is low post because mostly clinkers are replaced by cheaper pozzolanic material.
- As free line present in the cement is removed and hence resistance to chemical attack increases, making it suitable for marine works.

CHAPTER-2-CONCRETE

1. PERMISSIBLE LIMITS FOR IMPURITIES IN WATER

Impurity	Permissible Limits
Organic	200 mg/L
Inorganic	3000 mg/L
Sulphates (SO_3)	400 mg/L
Chlorides (CI)	2000 mg/L for plain concrete work, 500 mg/L for reinforced concrete work
Suspended matter	2000 mg/L

2. WHY NOT TO USE SEA WATER

- Seawater generally contains 3 to 5% of dissolved salts of which 78% is NaCl and 15% chloride/sulphate of Mg^{+2}, this will cause alkali aggregate reactions.
- As per IS456 seawater cannot be used for RCC and PSC but can we use four PCC in unavoidable condition.
- Seawater cannot be use for PCC also if aggregates are all alkali reactive.
- salt in seawater may cause efflorescence and persistence dampness hence it should be avoided when appearance is important.
- although seawater slightly accelerates the setting time but reduces the 28 days strength by 10 to 20%.

3. COMPRESSIVE STRENGTH OF CONCRETE

- 3specimens of a sample are taken to report the strength and compressive strength is average of 3 specimens.

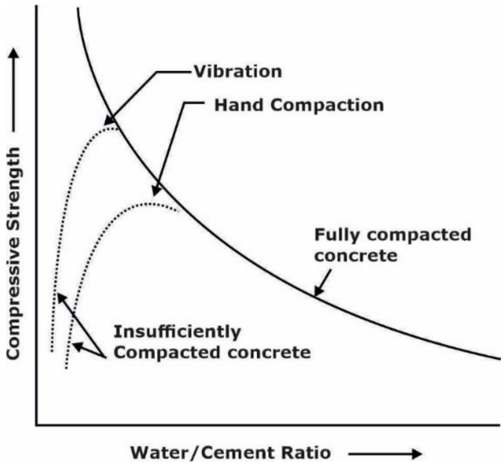
  $0.85(f_c)_{sample} \leq (f_c)_{specimen} \leq 1.15(f_c)_{sample}$
- standard cube sizes 150x150mm, standard cylinder sizes 150mm diameter and 300mm height. The faces in touch with molds are in touch with the plates of the machine.
- Compressive strength of a cylindrically specimen is it 0.8 times the compressive strength of a cubic specimen it is due to restraining effect of plates (because of friction) of the testing machine extends over the entire height of a cube but leaves unaffected a part of a test slender.
- Strength decreases with increase in size, however after a certain value it is almost constant. Compressive strength of concrete in structure is it 0.85 times strength in cylindrical specimen and 0.67 times strength in cubical specimen. IS code takes cubic strength as standard strength.

  Note: (a) Specimen tested in dry condition shows about 15% decrease in elastic modulus as compared to wet specimens this is explained by the fact that drying produces more micro cracks in the transition zone which affects behavior of curve for stress strain.

  (b) This is opposite to effect of moisture on the compressive strength which decreased by 15% when tested wet as compared to dry. Because moisture content in concrete produces lubrication effect and reduces the strength.

4. FACTORS AFFECTING STRENGTH OF CONCRETE

- **Water cement ratio:** Water content required to react completely with cement is 23%, rest of the water used for preparing paste will result in voids in the concrete matrix. But the water cement paste also work as lubricant for compaction, if the mixture is not fully compact it will not develop the strength fully. Strength of concrete is inversely proportional to w/c ratio, but when w/c ratio is very small then compaction become difficult, and strength gained is not equal to theoretically observed.



- **Size of specimen:** Smaller is the size of specimen better is its strength. Strength of cube is greater than strength of cylinder is greater than strength of building unit.
- **Size of aggregate:** Bigger is the aggregate lesser are the voids better should be the strength, but after a particular size further increase in size will decrease the strength because proper bonding between the aggregate is not possible because of the lesser surface area to the volume ratio.
- **Shape of aggregate:** round aggregate requires lesser paste to be bounded because have least voids but angular aggregate shows better interlocking so increases strength of concrete.
- **texture of aggregate:** more rough texture of aggregate better bonding between them.
- **Rate of loading:** faster is the loading more will be the strength because in slow loading there is more time for creep to occur as failure is governed by limiting strain not by stress.
- **Compaction/air voids:** strength of concrete decreases with increase in air voids in concrete which is due to improper compaction. Approximately 1% air voids will result in 5% strength reduction.

5. CREEP OF CONCRETE

- Under sustained compression (loading can be tensile also) deformation in concrete increases with time even though applied stress level is not changed, this time dependent component of strain is called creep.
- Creep depends on applied stress level, higher is the applied stress higher will be the creep, it is only due to dead load + permanent live load.
- creep occurs due to,(i) internal movement to adsorb water (ii) sliding between gel particles (iii) moisture loss and (iv) growth in microcracks.

- effect of creep are, (i) increase in deflection of beam, column and slabs, (ii) loss of prestress (iii) gradual transfer of load from concrete to the reinforcement in compression member. Due to create compressive strain in compression steel increases and tensile strain in tensile steel increases.
- Presence of compression reinforcement reduces creep, this effects sometime are beneficial like reduction of stress due to support movement.
- In general creep increases (i) when cement content is high (ii) aggregate content is low (iii) W/C ratio is high (iv) higher volume of voids (v) relative humidity is low (vi) temperature is high (vii) size or thickness is small (viii) loading occurs at early age (ix) load in sustained over long period of time.

6. SHRINKAGE OF CONCRETE

- It results from volume change in concrete, similar to creep it also introduces time dependent strain but shrinkage strain are independent of applied stress.Also shrinkage is reversible to great extent, alternate dry and wet processes will results in alternatevolume change in concrete.All factors related to material properties, composition of mix, curing, environmental condition, member size, that effect creep also effects in shrinkage.
- **Types of shrinkage**:

  chemical shrinkage:this is caused due to chemical reaction (hydration of cement), as you know absolute volume of unhydrated material is more than absolute volume of hydrated material.At early stage it results in volume reduction and at later stages with causes void formation.

  plastic shrinkage:it occurs due to loss of moisture from top surface, cracks genrated are generally on the top surface and it is a short-term process.

  autogenous shrinkage:it results in volume reduction with no moisture transfer from outside, this is mainly due to self-desiccation of cement (extreme state of dryness).This results in rise of capillary pressure and occurs in early days.It increases with increasing grade of concrete.

  drying shrinkage: contraction of harden concrete due to loss of water from the pores.It is a long-term process it increases with decreasing grade of concrete.
- For normal concrete, generally drying shrinkage dominates.
- half of the totalshrinkage occurs in first half month and 3/4thin first six month, in absence of data shrinkage strain for design shall be taken as $3\text{x}10^{-4}$.

7. MATURITY OF CONNCRETE

Strength of concrete depends on time period of curing end temperature maintained during Curing for early period of hydration.

$$\text{Maturity}=\sum(time \times temperature)$$

temperature is taken starting room -11°C, because experimentally hydration of concrete stops below -11°C.

$$\%\, strength\ of\ concrete = A + B\log_{10}(maturity \times 10^{-3})$$

8. WORKABILITY OF CONCRETE

- Workability is the amount of work required to produce full compaction.
- Consistency indicates the fluidity or mobility. it must be noted that workability is different from consistency optimum workability of concrete will be dependent on the type of job situation.
- The important factors affecting workability are:
  - (i) water content: higher is the water content better is fluidity of the mix, water act as a lubricant. For better workability more water is to be added but adding only water will increase water cement ratio which reduces strength so both water as well as cement must be added in the same ratio as that of the original mix.
  - (ii) Aggregate sites: for larger size aggregates total surface area to be wetted per unit volume of the aggregate is lesser, so additional paste is available to help lubrication.
  - (iii) shape of aggregate: rounded aggregates give better workability. Angular,elongated or flaky aggregates make concrete harsh.
  - (iv) mix proportion and grading of aggregate: better is the grading lesser will be the voids to be filled by the paste so more paste is available to work as lubricant
  - (v) surface texture of aggregate: smoother is the surface of aggregate better is its work ability.

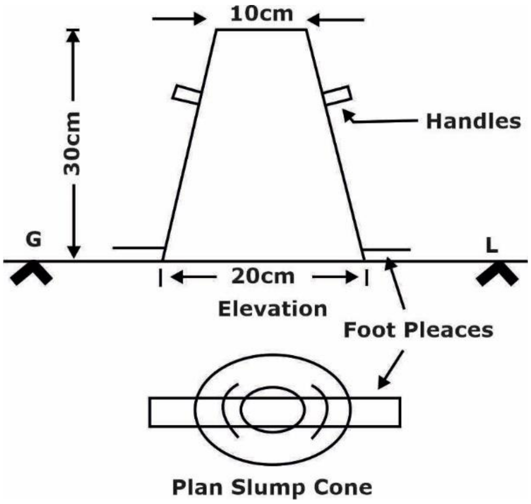
9. Mass concreting

- During massconcreting, concrete is placed in layers of 350–450mm, before placing the concrete on next layer previous surface must be properly cleared with waterjet and scrubbing by airbrush.
- Concrete subjected to lateral thrust, bond bars and bond stones are provided to form a key between different layers.
- In case of mass concreting due to large heat of hydration trapped within the concrete mass, it tries to expandand hence tensile stresses develops on outside and compressive in interior which causes cracks on the surface.
- To avoid these cracks, we use low heat of hydration cements, external ice bags are placed to lower the surface temperature.

10. VARIOUS TESTS FOR WORKABILITY ARE:

Slump Test

- Slump test is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory or at site of work.
- It is not a suitable method for very wet or very dry concrete and stiff mix.
- Maximum size of aggregate is limited 38mm.



Compaction Factor Test

- In the compaction factor test the degree of workability is measured in terms of internal energy required to compact the concrete thoroughly.
- A compaction factor increase is workability also increases.
- The compacting factor test is designed primarily for use in the laboratory, but it can also be used in the field.
- The degree of compaction called the compacting factor is measured by the density ratio i.e., the ratio of the density actually achieved in the test to the density of the same concrete fully compacted.

Vee Bee Consistometer

- This test consists of a vibrating table, metal pot, sheet metal concrete and a standard iron rod.
- The time required for the shape of concrete to change from slump concrete shape to cylindrical shape in seconds is known as Vee Bee Degree.
- This method is very suitable for very dry concrete whose slump value cannot be measured by slump test but the vibration is too vigorous for concrete with a slump greater than about 50 mm.
- In this test, more is the time lesser will be the workability.

Flow Test

- This test is appropriate for concrete having very high work ability including flowing concrete.
- the flow of concrete is the percentage increase in diameter hope spread concrete due to falling off table from 12.5mm @ of 60 RPM for 15 times.The spread or the flow of the concrete is measured, and this flow is related to workability.
- This is a laboratory test which gives an indication of the quality of concrete with respect to consistency,cohesiveness and the proneness to segregation.

Uses of concrete having different consistency:

Degree of workability	Slump (mm)	Compacting factor		Use for which concrete is suitable
Very low	-	0.78	0.90	Roads vibrated by power-operated machines. At the more workable end of this group, concrete may be compacted in certain cases with hand-operated machines.
Low	24-75	0.85	0.87	Roads vibrated by hand-operated machines. At the more workable end of this group, concrete may be manually compacted in roads using aggregate of rounded or irregular shape. Mass concrete foundations without vibration or flighty reinforced sections with vibration.
Medium	50-100	0.92	0.935	At the less workable end of this group, manually competed flat stables using crushed aggregates. Normal reinforced concrete manually compacted and heavily reinforced sections with vibrations.
High	100-150	0.95	0.96	For sections with congested reinforcement, Not normally suitable for vibration, for pumping and tremble placing.
Very high	-	-	-	Flow table test is more suitable.

11. COMPACTION

- Compaction is a process of removal of entrapped air and uniform placement of concrete to form a homogeneous dense mass. Density strength durability impermeability obse concrete depends on compaction.
- compaction by mechanical vibration reduces internal friction between the different particles of concrete by imparting oscillations to particles and dust compacts the concrete.

  different types of mechanical vibrators are:
- **internal vibrator/needle/poker/immersion vibrator:** it is generally best suited for construction work as all the energy is directly transferred to concrete.A steel tube with eccentric loading inside is rotated with external motor and this tube is inserted in concrete itself.Do not try to move concrete with vibrator, it will cause segregation of concrete mix.
- **Form or external vibrators**: clamped rigidly do the form work at the predetermined points so that both concrete and form work both are vibrated. it is used where needle vibrator cannot

be inserted like dense RCC or narrow walls or columns. you can compact up to 450 mm from surface. This has to be moved from surface to surface, it requires more power to give same degree of compaction effect as given by the internal vibrator.

- **vibrating tables**: it is very efficient in compacting stiff and harsh concrete mixes, required for precasting elements, it is also used for laboratory compaction of test specimens.
- **surface vibrator or screed board vibrator**: it is placed directly on the surface of concrete mass shallow depth.It is mainly used in case of road construction, it should not be used when depth of the concrete is more than 150mm.

12.NONDESTRUCTIVE TEST

- Nondestructive tests do not cause any damage to the structure or specimen and hence save a lot of time and money.They are more or less done at same location to know variation of property with time.
- **rebound hammer test:** it is done to find out the compressive strength of concrete.Its principle is, rebound of an elastic mass depends on hardness of surface against which it strikes.The compressive strength can be read directly from the graph provided on the body of hammer.Surface of specimens should be smooth.For old concrete surface hardness will be more as compared to strength of interior because in old concrete due to carbonation at surface hardness increases and it will overestimate the strength of concrete.
- **penetration test:** it is done to determine resistance of concrete to penetration by a steel Rod, driven by a fixed amount of energy.It is used to assess the compressive strength of concrete; depth of the penetration is inversely proportional to strength.
- **ultrasonic pulse velocity test:** principal of this test is velocity of sound in a solid material is a function of modulus of elasticity and density of material.The instruments consist of a pulse transmitter and receiver which are held on opposite faces.velocity of a wave is calculated which is the correlated to the strength of concrete, type and amount of aggregate affects the pulse velocity, paste has lesser velocity as compared to that ofaggregate. Saturated sample has more velocity as compared to dry sample.If reinforcement is present in path, then proper adjustment is to be made for corrections.It can estimate strength and homogeneity of concrete.thisdetermines the dynamic modulus of elasticity.
- **pull out test:** this test measures the force required to pull out a precast metal entered earlier with enlarged end.Pull out forces related to the compressive strength of concrete; it actually measures the shear strength of concrete.This test has to be preplanned and damage caused to the location has to be maintained.

13.DEFECTS IN CONCRETE

Bleeding of Concrete

- Bleeding is also known as water gain it is a type of segregation in which some of the water in the mix tends to rise to the surface of freshly prepared or placed concrete. it is caused due to inability of solid constituents to hold all the mixing waters when settles downward, water being lightest hence comes to the top.
- Due to bleeding water comes up and accumulates at the surface, along with water some cement will also come out.This is observed in case of rich mix and where excessive vibration is done.
- Bleeding leads to creation of pores inside concrete hence causes decrease in strength.
- Bleeding can be reduced by using finer cement, by use of uniformly graded aggregates, air entraining agents and pozzolana, by breaking continuous water channel.

Segregation

- It is the separation of the constituent material of concrete.In a good concrete all the constituents are distributed uniformly to make a homogeneous mixture.
- Cohesive and fatty characteristic of matrix does not allow aggregate to fall apart.
- Causes of segregation are excessive water, dropping concrete from height, badly designed mix, poor aggregate grading, concrete carried away for long distances.
- If the mix is too wet then excessive vibration will make aggregate to settle down, it can be avoided by air entrainment using dispersing agent, finer coarse aggregates.
- Do not use vibrator to spread the mixture.

Crazing

- Development of fine random cracks on the surface of concrete due to difference in shrinkage between surface and interior.These are not harmful apart from appearance.Their depth is less than 12mm.

Cracks

- Cracks cannot be completely prevented but can be minimized, use of unsound material high w/c ratio, bad jointing, freezing, thermal effects etc. leads to cracks.This makes the concrete less durable.
- when more water is used,coarse aggregates will settle down and upper layer will have more pores as the water quantity is high.This porous concrete could not withstand sinkage stresses and will lead to cracks.
- shrinkage cracks due to early Loss of water, water is absorbed by dry aggregates, dry shuttering or hot sunny day. Which leads to shrinkage cracks.
- alkali aggregates reactions, when expensive compound is formed by reaction of silica from aggregate and alkali from cement in presence of moisture in concrete will lead to cracks and disruption of concrete.

- freezing and thawing, if W/C ratio was high concrete would be more porous and rainwater can percolate easily inside and when temperature goes below freezing point these voids tried to expand to accommodate the volume change.

14.Underwater concreting

- **Bottom dump truck:** In this method a bucket of concrete is taken through water in a watertight box or bucket and on reaching the final place of deposition the bottom is made open by some mechanism.Some amount of cement is washed off and concrete masses is full of voids.
- **Tremie pipe:** This is the best method for underwater concreting.The pipe of 200mm diameter is used with funnel at top. Firstly, pipe is filled with concrete and then a small jerk is given after placing the pipe at desired location, so that bottom lock isunlocked, and concrete is placed, now keeping the end of pipe submerged in concrete we fill the pipe again and again till desired depth is reached.Concrete in inner layer is not affected by water except the outer layers. concrete automatically get compacted by water pressure.Here concrete is used having very high slump about 150 to 200.

15.High performance concrete: This is not any special type of concrete but are created by using one or more cementitious materials such as Flyash, silica flumes or granulated blast furnace slag and usually a superplasticizer.

their basic properties are

1. it has very less permeability, high toughness and good workability.
2. high durability and energy adsorption capacity for earthquake resistant structure.

16.Ferrocement: the term ferrocement implies the combination of ferrous product with cement, generally this combination is in the form of steel wires meshes embedded in the Portland cement motor.

its properties are

1. it has high strength per unit mass
2. capacity of to resist shockload
3. it is impervious
4. these can be constructed without using formwork.

CHAPTER-3-STEEL & MISCELLANEOUS MATERIALS

1. Steel

The carbon content in steel lies between cast iron (2-4 percent) and wrought iron (0.15 percent maximum). Usually, it is between two percent. Carbon in excess of percent does not combine with iron and exists as free graphite. This makes the dividing line between cast iron and steel where former possesses free graphite whereas later does not. As the carbon content increases steel becomes harder and tougher. Steel possesses sufficient tensile and compressive strength unlike cast iron (good compressive strength but poor tensile strength) and wrought iron (good tensile strength by virtue of fibrous nature).

- **Manufacturing of steel**

  The processes commonly used for manufacturing of steel are

  (1) Bessemer process

  (2) Cementation process

  (3) Crucible steel process

  (4) Duplex process

  (5) Open hearth process

  (6) Electric process

- **Defects in steel:** The commonly occurring defects in steel are

  (i) Cavities or blow holes: These are formed by trapping of gases in the molten mass which produce cavities on solidification.

  (i) Cold shortness: Higher percentage of phosphorus causes this defect in steel. The steel cracks when worked in cold state

  (ii) Red shortness: Excess amount of sulphur in steel causes cracking of a steel when worked in hot state.

  (iii) Segregation: This defect refers to the separation of some constituents of steel solidifying at an early stage.

- **Properties of mild steel:** Mild steel possesses the following properties.

  (1) It can beEasily forged and welded

  (ii) It cannot be easily hardened and tempered

  (iii) It has a fibrous structure

  (iv) It is malleable and ductile

  (v) It is susceptible to rusting

  (vi) it has specific gravity of 7.70 – 7.80

2. PAINTS

The paints are coatings of fluid materials, and they are applied over surfaces of timber and metal to protect the surface from weathering effects. Also, it gives a good appearance and a smooth surface for easy cleaning.

- **Ingredients of an oil paint:**

An oil paint essentially consists of the following ingredients:

(i) **Base:** A base is a solid substance in a line state of division, and it forms the bulk of a paint. It determines the character of the paint and imparts durability to the surface which is painted. It reduces shrinkage cracks formed on drying and it also forms an opaque layer to obscure the surface of material to be painted. Common bases are white lead, red lead, oxide of zinc and zinc white, Lithophone etc.

(ii) **Vehicles:** The vehicles are the liquid substances which hold the ingredients of a paint in liquid suspension. They help in even spreading of paint and acts as a binder material so that the paint may stick to the surface properly. Common vehicles used in the paint are Linseed oil, Tung oil, Poppy oil, Nut oil etc.

(iii) **Driers:** These substances accelerate the process of drying. A drier absorbs oxygen from the air and transfers it to the linseed oil, which in turn gets hardened. Litharge is the most commonly used drier.

(iv) **Colouring pigments:** Pigments are added to the paint to impart desired colour. They might be natural or artificially made.

(v) **Solvents:** The function of a solvent is to make the paint thin so that it can be easily applied on the surface. It also helps the paint in penetrating the porous surfaces. The most commonly used solvent is the spirit of turpentine.

- **Different Varieties of Paint:**

Following are the different types of paints available in the market.

(i) Aluminium paint: The very finely ground aluminium is suspended in either quick drying spirit varnish or slow-drying oil varnish as per requirement. The oil evaporates and a thin metallic film of aluminium is formed on the surface.

(ii) Anticorrosive paint: This paint essentially consists of oil and a strong drier. A pigment such as chromium oxide or lead or red lead or zinc chrome is taken and after mixing it with some quantity of very fine sand, it is added to the paint.

(iii) Asbestos Paint: This type of paints are applied on the surfaces which are exposed to the acidic gases and steam.

(iv) Bituminous paint: This paint is prepared by dissolving asphalt in any type of oil or petroleum. The paint presents a black appearance, and it is used for painting ironwork under water.

(v) Cellulose paint: This paint is prepared from nitro-cotton. Celluloid sheets, photographic films, etc. It hardens by evaporation of a thinning agent. It gives a flexible, hard and smooth surface. Also, the painted surfaces with cellulose paint can be washed and easily cleaned.

(vi) Cement paint: This paint consists of white cement, pigment, accelerator and other additives. It is available in dry powder form. The cement paint is available in a variety of shades, and it exhibits excellent decorative appearance. It is waterproof and durable.

(vii) Colloidal paint: No inert material is mixed in this type of paint. It requires more time to settle and in the process of settlement, it penetrates through the face. It may be used for interior as well as exterior walls.

(viii) Emulsion paint: A variety of emulsion paints is available. It contains binding materials such as polyvinyl acetate, synthetic resins, etc. This paint is easy to apply and it dries quickly in about 1 to 2 hours.

(ix) Enamel paint: This paint is available in different colours. It contains white lead or zinc white, oil, petroleum spirit and resinous matter. It dries slowly and forms a hard and durable surface.

(x) Graphite paint: The paint presents a black colour and it is applied on iron surfaces which come in contact with ammonia, sulphur gases, chlorine etc.

(xi) Luminous paint: This paint contains calcium sulphide with varnish. The surface on which luminous paint is applied shines like radium dials of watches after the source of light has been cut off.

(xii) Oil paint: This is ordinary paint and it is generally applied in three coats of varying composition. They are respectively termed as primes, undercoats and finishing coats. This paint is cheap and easy to apply and it possesses good opacity and low gloss.

(xiii) Plastic paint: This paint contains the necessary variety of plastics. The paint possesses a pleasing appearance and it is attractive in colour. It is widely used in showrooms and auditoriums.

3. VARNISHES

The term varnish is used to indicate the solution of resins or resinous substances prepared either in alcohol, oil or turpentine.

- **Following are the characteristics of an ideal varnish**

(i) It should render the surface glossy.

(ii) It should dry rapidly and present a finished surface which is uniform in nature and pleasing in appearance.

(iii) The colour of varnish should not fade away when the surface is exposed to the atmospheric actions.

(iv) The protecting film developed by varnish should be tough, hard and durable.

(v) It should not shrink after drying.

- **Ingredients of a Varnish:**

Following are the ingredients of a varnish:

(i) Resins or resinous substances: The commonly used resins are copal, lac, shellac and rosin.

(ii) Driers: The function of a drier in varnish is to accelerate the process of drying. The common dryers used in varnishes are litharge, white copper and lead acetate.

(iii) Solvents: Depending upon the nature of resin, the type of solvent is decided. For Copal boiled linseed solvent is used. For lac and shellac, the Methylated spirit of wine is used as solvent. While for rosin, turpentine is used as solvent.

- **Types of Varnishes:**

  Varnishes are classified on the basis of the type of solvent used. They are basically of four types:

  (i) Oil varnishes: Linseed oil is used as solvent.

  (ii) Spirit varnishes: The methylated spirit of wine is used as a solvent.

  (iii) Turpentine varnishes: Turpentine is used as solvent.

  (iv) Water varnishes: Hot water is used as solvent.

4. ADMIXTURES:

- Admixtures are chemical compounds other than water, aggregates, hydraulic cement and additives like pozzolana, fiber R/f used as ingredient of concrete.
- it is added before or during mixing to modify one or more property of concrete in wet and hardened state.
- admixtures are liquid generally because liquids are better to mix.
- admixtures do never replace the good workmanship or good material to be used.
- reasons for adding admixture to the concrete are, to increase workability, to reduce water content, to accelerate or retard setting of concrete and increase resistance to the chemical attack.
- **plasticizers(water reducers):**plasticizers mainly fluidify the mix and improve the workability for a given water content or help decreasing the water content for a given workability.**Ex are ligno-sulphonic acid,hydroxylated carboxylic acid.**

  when plasticizers are added they get adsorbed on the cement particles, adsorption of charged polymer on cement creates repulsive force between particles and flocculated structures changes to dispersed and water entrapped in voids of cement structure is free to help in improve fluidity.
- **Superplasticizers**: they are chemically distinct from normal plasticizers, but the action is basically same. use of superplasticizers can reduce water requirement by 30% as compared to plasticizers which can help reduce water quantity by 15%.Finer is the cement more will be the plasticizer required. **examples are sulphonated melamine formaldehyde.**It is used in case of flowing concrete, self-compacting concrete and production of high-performance concrete.

- **Airentrainers:** air entraining agent introduces air in the form of minute air bubbles distributed uniformly throughout the cement paste, to improve resistance against freezing and thawing of hardened concrete, to improve workability in case of harsh mix or whereas fines are absent.It also helps prevent bleeding. Air entrainer reduces the strength, 1% air bubble will reduce 5% compressive strength.
- **Accelerators:**These admixtures speed up the chemical reaction of cement and water hence accelerate the rate of setting or early gain of strength.also, it increases initial heat of hydration.**Ex. of accelerator are NaCland Na_2SO_4 and NaOH etc.**Used where early setting or high initial strength is required. concreting is taking place in very cold region.
- **Note: chloride-based accelerator promote corrosion of R/f steel, so avoid using this for RCC.**
- **Retarders:** These slow down the chemical process of hydration so concrete remain plastic and workable for a longer time. examples are gypsum, sugar.Overdosing candelay setting for days.Used when concreting is done in hot weather, to prevent cold jointingdue to duration of placing, to transport concrete from one place to another.Note: $CaCl_2$ is added up to 2% it acts as it accelerator but on increasing the proportions it acts as retarder.

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