LEARNING MATERIAL

SEMESTER & BRANCH: 6TH SEMESTER CIVIL ENGINEERING

THEORY SUBJECT: CONCRETE TECHNOLOGY (TH-4A)

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Concrete Technology

Cement + Sand + Aggregate — Mix design — Max characteristic strength

Fine aggregate, coarse aggregate.

→ Concrete is the most widely used man made construction material in the world.

→ It is obtained by mixing cementing materials & some times admixtures as required proportion. The mixture when placed in forms & allowed to cure, hardens into a rock like mass i.e known as concrete.

→ The hardening is caused by chemical reaction occur between water & cement & it continues a long times.

→ The strength, durability & other characteristic of concrete depends upon the properties of it's ingredients used in the mixture.

* Grades of concrete:-

→ Concrete is generally graded according to the compressive strength.

→ The various grade of concrete are mentioned in IS 456-2000 & IS 1343-1980.

→ In the designation of concrete mix the letter 'M' refers to the mix design & the number of specified characteristic strength of 150mm cubes at 28 days expressed in MPa (N/mm^2)

→ The concrete of grade M5 & M7.5 is suitable for simple foundations, foundations for masonry walls / other simple & temporary reinforc-ed concrete construction.

→ The concrete of grade lower than M_{15} is not suitable for reinforced concrete work.

→ The concrete of grade lower than M_{30} is not suitable for prestressed concrete work.

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Group	Ordinary concrete			Standard concrete								High strength concrete			
Grade designation	M_{10}	M_{15}	M_{20}	M_{25}	M_{30}	M_{35}	M_{40}	M_{45}	M_{50}	M_{55}	M_{60}	M_{65}	M_{70}	M_{75}	M
Specified characteristic strength at 28 days (MPa)	10	15	20	25	30	35	40	45	50	55	60	65	70	75	8
Mix proportion	1:3:6	1:2:4	1:1.5:3	1:1:2	Design mix										

Note -

$M_5 = 1:5:10$

$M_{7.5} = 1:4:8$

Uses of concrete grade :-

A) M_5, M_{10}, M_{15} → These are used for PCC (plain cement concrete) work such as leveling course, bedding for footing etc.

B) M25, M30, M35 ⇒ These are used for RCC (reinforced cement concrete) like foundation, footings, columns, beams, slab etc.
M40

C) M40 ⟶ This is used for pre-stressed concrete work : slabs, beams, column, footing etc.

D) M45, M50 ⇒ These are used for RCC, runways, concrete roads, prestressed concrete girder RCC column, prestressed beam.

E) M55 → This is used for prestressed concrete girder & pier.

F) M60, M65, M70, M75 ⟶ These are used for RCC work where M80 high compressive strength is required such as high rise building, long span bridge, dam, coastal construction etc.

* Advantages of concrete :-

1. Concrete is economical in the long run as compared to other engineering materials.
2. Concrete posses a high compressive strength & the corrosive & weathering effects are minimal.
3. The newly mixed concrete can be easily handled moulded & formed in any shape (or) size.
4. It is strong in compression & has unlimited structural applications - in combination with steel reinforcement.
5. Concrete can even be sprayed on & filled into fine cracks for repairs.

6. concrete can be pumped & hence it can be laid in difficult positions.

7. It is durable, fire resistant & required very little maintenance.

* Disadvantages of concrete:-

→ The following are the disadvantages of concrete:-

(i) Concrete has low tensile strength, hence crack easily. Therefore concrete is to reinforced with steel bars (or) meshes (or) fibers.

(ii) Fresh concrete shrinks on drying & hardened concrete expands on wetting.

(iii) Concrete expands & contracts with the change in temperature. Hence expansion joints have to be provided to avoid the formation of cracks due to thermal movement.

(iv) Concrete under sustained loading undergoes creep, resulting in the reduction of prestress in the prestressed concrete construction.

(v) Concrete is entirely impervious to moisture & contains soluble salts which may causes efflorescence.

* Properties of concrete:-

→ Concrete making is not just a matter of mixing ingredients to produce a plastic mass, but good concrete has to satisfy performance requirement in the plastic state.

→ In the plastic state the concrete should be workable & free from bleeding & segregation.

→ Segregation is the separation of coarse aggregate from concrete & bleeding is the separation of cement past from concrete.

→ Segregation & bleeding result in poor quality concrete.

→ In the harden concrete should be strong, durable & impermiable.

→ Among all the properties of concrete the compressive strength is consider to be most important.

Chapter-II Cement

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→ cement is a building material which is used in construction work.

→ The cement commonly used is portland cement.

→ The mixture of cement, sand & water is known as cement mortar.

→ when aggregate is added to this paste it is converted to concrete.

→ The ingredients of concrete can be classified in to two groups i.e active & inactive.

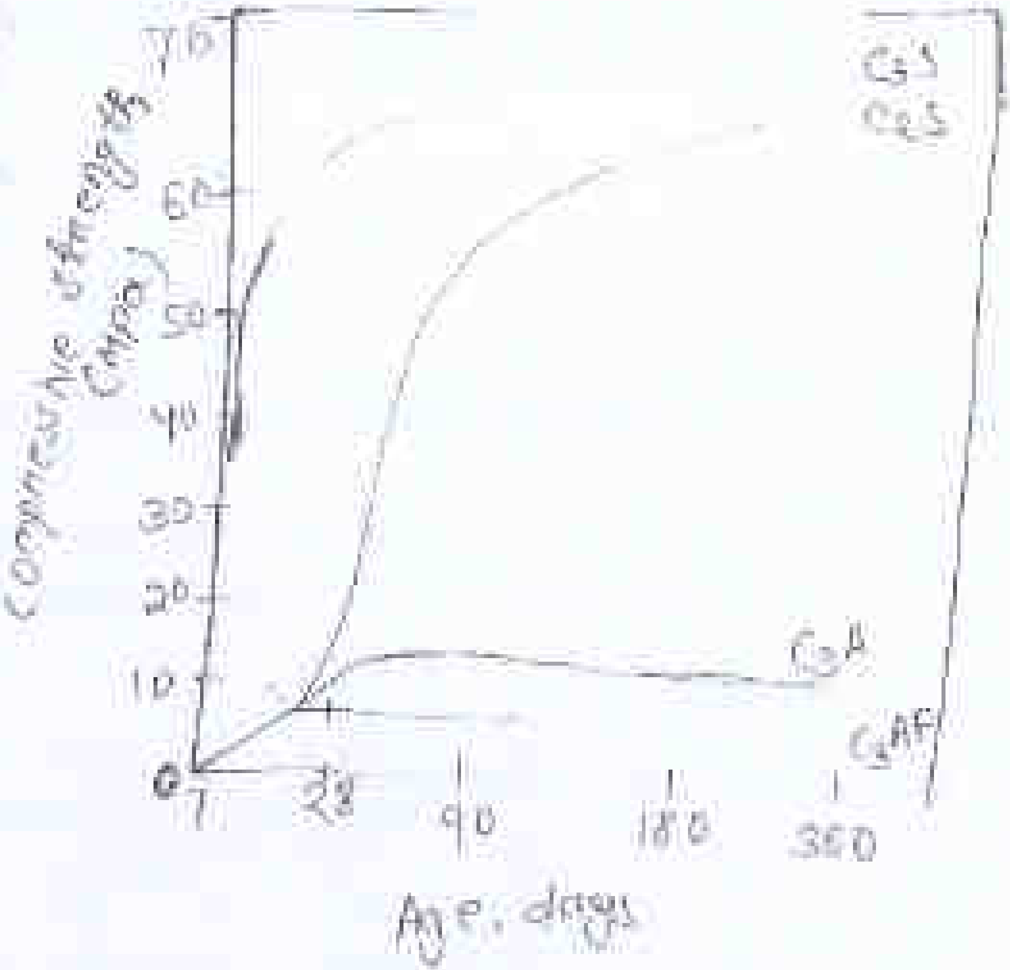
→ The active group consists of cement & water where as the inactive group comprises fine & coarse aggregate.

* Cement compounds :-

- Tricalcium silicate (C_3S) → (25-50)%
- Dicalcium silicate (C_2S) → (20-45)%
- Tricalcium aluminate (C_3A) → (5-12)%
- Tetra calcium alumino ferrite (C_4AF) → (6-12)%

* Basic Pro-

Basic properties of cement compounds



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→ The two silicates namely C_3S & C_2S which together constitute about 70-80% of the cement, control the most of the strength giving properties.

→ Upon hydration both C_3S & C_2S give the same product called calcium silicate hydrate ($C_3S_2H_3$) & calcium hydroxide.

→ Tricalcium silicate (C_3S) having a faster rate of reaction accompanied by greater heat evolution, develops early strength.

→ On the other hand dicalcium silicate (C_2S) hydrates & hardens slowly & provide much of the ultimate strength.

→ It is likely that both C_3S & C_2S contribute equally to the eventual strength of the cement.

→ C_3S & C_2S need approximately 24 & 21 percent by weight of water.

→ For chemical reaction C_3S liberates nearly three times as much calcium hydroxide on hydration as C_2S.

→ C_2S provide more resistance to chemical attack.

→ Thus a higher percentage of C_3S provides C_3S results in rapid hardening with an early gain in strength at a higher heat of hydration.

→ On the other hand, a higher percentage of C2S results in slow hardening, less heat of hydration & greater resistance to chemical attack.

→ The compound tricalcium aluminate (C_3A) is characteristically fast reacting with water & may lead to an immediate stiffening of paste & this process is known as flash set.

→ The role of gypsum added in the manufacture of cement is to prevent such a fast action.

→ C_3A reacts with 40% of water by mass & this is more than that required for silicates.

→ However, the amount of C_3A in cement is comparatively small; the net water required for the hydration of cement is not affected.

→ It provides weak resistance against sulphate attack & its contribution to the development of strength of cement is perhaps less significant than the silicates.

→ In addition the C_3A is responsible for the highest heat of evolution, both in the initial period & in the long run.

→ Like C_3A, C_4AF hydrates rapidly but its individual contribution to the overall strength of cement is insignificant. However C_4AF is more stable than C_3A.

→ In terms of oxide composition, a high lime content generally increases the setting time & results in higher strength.

→ A decrese in lime content reduces the strength of concrete.

→ A high silica content prolongs the setting time & gives more strength.

→ The presence of excess unburnt lime is harmful, since it results in delayed hydration causing expansion unsoundness.

→ Iron oxide is not a very active constitue nt of cement & generally act as catalys & helps the burning process.

→ The presence of Iron oxide derives the cement grey in colour.

→ Magensia, if present in large quantity, then it leads to unsoundness.

Hydration of cements :-

→ The extent of hydration of cement and the resultant micro structure of hydrated cement influences the physical properties of concrete.

→ The microstructure of hydrated cement is more or less similar on to silicate phases

→ When the cement comes in contact with water, the hydration of cement proceeds both inward and out ward in the sence that the unhydration products get deposited on the outer periphery and the nucleus of the unhydrated cemen inside gets gradually diminished in volume.

→ The reaction proceeds slowly for 2-5 hours [called induction or dormant period] before according accelerating as the surface skin breaks

→ At any stage of hydration having, the cement paste consist of gel (a finely grained product of hydration having large surface area collectively called gel) the remnant of unreacted cement, calcium hydroxide $Ca(OH)_2$ and water, besides some other minor compound

→ The crystals of various resulting compounds from an interlocking random three dimensional network gradually filling the space originally occupied by the water, resulting in stiffening and subsequent development of strength as shown in accordingly. the hardened cement paste has a porous structure the pore size varying from very small (4 x 10^-9 m) to a much larger value, the pores being called gel pores, may and capillary pores, respectively.

→ The pore system inside the hardened cement paste may or may not be continuous.

→ As the hydration proceeds the deposit of hydration products on the original cement grain makes the diffusion of water to unhydrated nucleus more and more difficult thus reducing the rate of hydration with time.

The reactions compounds of cement and their products may be represented of symbolically.

$2(3CaO \cdot SiO_2) + 6H_2O \rightarrow 3CaO \cdot 2SiO_2 \cdot 3H_2O + 3Ca(OH)_2$

or symbolically.

$2C_3S + 6H \rightarrow C_3S_2H_3 + 3Ca(OH)_2$

$2(2CaO \cdot SiO_2) + 4H_2O \rightarrow 3CaO \cdot 2SiO_2 \cdot 3H_2O + Ca(OH)_2$

$2C_2S + 4H \rightarrow C_3S_2H_3 \rightarrow Ca(OH)_2$

$2C_3A + 21H \rightarrow C_4AH_{13} + C_2AH_8 \rightarrow 2C_3AH_6 + 9H$

$C_4AF + 7H \rightarrow C_3AH_6 + CFH$

Reactions in the presence of gypsum are.

$C_3A + 32H + 3CaSO_4 \rightarrow C_3A \cdot 3CS \cdot H_{32} \rightarrow C_6AS_3H_{32}$

(trisulphate hydration)

$C_3A + 18H + CaSO_4 \rightarrow C_3A \cdot CS \cdot H_{18}$ ... ettringite

(Monosulfate hydrate)

→ The above equations (with C=CaO, S=SiO₂ and H=H₂O) only refer to the process in which the cement compounds react with water to form colloidal dimensions (1nm than 2Nm) to 10nm or more.

→ The calcium hydroxide (Ca(OH)₂) liberated during the reaction of silicate hydrate phase crystallizes in the available free space. The product $C_3S_2H_3$ representing calcium silicate hydrate, a gel structure, is normally expressed by hyphenation C-S-H, which signifies that it is not a well-defined compound.

→ The simplistic scanning-electron micrograph of hydration of cement.

→ The hydration of C_3S produces a comparatively lesser quantity of C-S-H than that produced by C_2S. On the other hand, C_3S liberates nearly three times as much calcium hydroxide on hydration as C_2S. However, $Ca(OH)_2$ is not a desirable product in the concrete mass as it is soluble in water and gets leached out making the concrete porous.

→ The only advantage of $Ca(OH)_2$ is its being alkaline in nature and maintaining a pH value of around 13 in the concrete. A pH value at this level passivates reinforcing steel against corrosion. In general, the quality and density of C-S-H produced due to hydration of C_3S is slightly inferior to that formed by hydration of C_2S.

→ The hydration product C_2S is rather dense and its specific surface is higher.

On hydration of C_3A a calcium aluminate system $CaO-Al_2O_3-H_2O$ is formed. The cubic compound C_3AH_6 is probably the only stable product.

→ Hydration of C_3AF is belived to form a system $CaO-Fe_2O_3-H_2O$. A hydrated calcium ferrate of the form C_3FH_6 is comparatively more stabl. In the presence of gypsum depending upon the concentration of aluminate and sulfate irons in the solution phase, the precipitating crystaline product is either calcium aluminate trisulfate hydrate ($C_6S_3H_{32}$) or calcium aluminate monosulfate hydrate. The product calcium aluminate trisulfate known as ettringite, which crystallizes as short prismatic needles on account of high sulfate aluminate are iron ratio in the solution phase during first hour of hydration when surface solution gets depleted aluminate irons concentration increases due to renewed hydration and the aluminate is gradually converted into monosulfate which is the final product of hydration of portland cement containing more than five percent C_3A.

Rate of hydration:-

→ As mentioned earlier, the reaction of the compound C_3A with water is very fast in that flash setting i.e stiffening without strength development, can occure because the C-A-H phase prevents the hydration of C_3S and C_2S. However, some of the compound in the clinker dissolves immediately in and the sulfate ions in the solution react with C_3A of form insoluble calcium sulfoaluminate. which deposits on the surface of the C_3A to form a protective colloidal membrane and thus retard the direct hydration reaction.

When all the surface is consumed, hydration can accelerate. The amount of sulfate must, therefore, be carefully controlled to leave little excess C_3A to hydrate directly.

→ The hardening of C_3S appears to be catalyzed by C_3A so that C_3S becomes almost solely responsible for the gain of strength up to about 28 days by growth and interlocking of C-S-H gel.

→ The later age increase in strength is due to the hydration of C_2S. The rate of strength development can, therefore, be modified by changes in the relative quantities of these compounds.

Mechanism of Hydration

→ C_3A react from beneath the thin membrane of calcium sulfoaluminate formed on the C_3A surface.

→ Owing to the larger volume of calcium sulfoaluminate pressure develops and the membrane eventually bursts, allowing the sulfate in solution to come in contact with unreacted C_3A to reform the membrane.

→ The cyclic process continues until all the sulfate in solution is consumed, whereupon the cell can hydrate directly at a faster rate and the transformation of calcium sulfoaluminate into needle like monosulfate crystals leads to the loss of workability and to setting.

→ This gives rise to the induction period which ends when the protective membrane is disrupted.

→ Although the reaction between C_3S and water proceeds at the same time in a properly retarded cement

→ The end of induction period of C_3S hydration coincides with the point at which the sulfate in solution is no longer available for reaction.

→ Setting now is due to the simultaneous growth of aluminate hydrate, monosulfate and silicate hydrate in the inter-particle space.

→ The above theory is termed as protective membrane hydrat theory.

Effect of Admixtures on hydration:—

→ Some admixtures may reduce the electric repulsion between the individual positively charged hydrating cement particles so that they approach closer and stick to form agglomerates which grow and eventually settle out.

→ This process is termed flocculation and the agglomerates floc.

→ The anions may flocculate the colloidal membrane thus making more permeable.

* **Abram's law :- Water to cement and compressive strength :-**

→ Cement of average composition requires about 25% of water mass for chemical reaction.

→ In addition, an amount of water is needed to fill the gel pores.

→ Nearly 100 years ago, Duff Abram discovered the direct relationship between water to cement ratio and strength that is lesser the water used higher the strength of concrete, since too much water leaves lots of pores in the cement paste.

→ According to Abram's law, the strength of fully compacted concrete at a given age and normal temperature is inversely proportional to the water cement ratio.

→ Here the water-cement-ratio is the relative weight of the water to the cement in the mixture.

→ For most applications water-to-cement should be betn 0.4 and 0.5, lower for lower permeability and higher strength.

→ In concrete lower water content results in very stiff mixture that are different to place.

→ The water to cement ratio is selected by engineer according to the requirement of place.

* **Physical properties of portland cement :-**

- Fineness
- Setting time
- Soundness
- Compressive strength
- Heat of hydration
- Specific gravity

→ The cement to be used in construction must have certain given qualities in order to play it's part effectively in a structure.

→ when these properties lie within a certain range then the cement performance will be satisfactory.

→ Also based on these properties it is possible to compare the quality of cement from different sources

→ The important physical properties of a cement are :-

1) Fineness :-

→ The fineness of cement is a measure of the size of particles of cement & is expressed in terms of specific surface area of cement.

→ It can be calculated by particle size distribution.

→ It is an important factor in determining the rate of gain of strength & uniformity of quality.

→ For a given weight of cement the surface area is more for a finer cement than a coarser cement.

→ Finer the cement, the higher the rate of hydration, as more surface area is available for chemical reaction.

→ This results in early development of strength.

→ If the cement is ground beyond the certain limit It's cementative properties may be adversely affected due to prehydration by atmospheric moisture.

→ As per Indian standard specifications the residue of cement should not exceed 10% when sieved

... IS sieve..

2) Setting time :-

→ cement when mixed with water forms paste which gradually becomes less plastic & finally a hard mass is obtained.

→ In this process the setting a stage is reached when the cement paste is sufficiently rigid to withstand a definite amount of pressure.

→ The time to reach this stage is known as setting time.

→ The time at which the cement paste loses it's plasticity is turned as initial setting time.

→ The time taken to reach the stage when the paste becomes a hard mass is known as final setting time.

→ It is essential for proper concreting that the initial setting time be sufficiently long for finishing operations i.e transporting & placing the concrete.

→ The setting time decreases with the rise in temperature upto 30°C & vice-versa.

→ For an ordinary portland cement the initial setting time should not be less than 30 minutes & final setting time should not be more than 600 min (10 hr).

→ A phenomenon of abnormal premature hardening within a few minutes of mixing the water is termed as flash set.

3- Soundness :-

→ The unsoundness of cement is caused by the undesirable expansion of some of it's constituents sometimes after setting.

→ The large change in volume results in disintegration / severe cracking

→ The unsoundness is due to the presence of lime & magnesia.

→ The free lime hydrates very slowly because it is covered by the thin film of cement which prevents direct contact between lime & water.

→ After the setting time, the moisture penetrates very slowly in to the free lime resulting in its hydration.

→ The unsoundness of cement may be reduced by :-

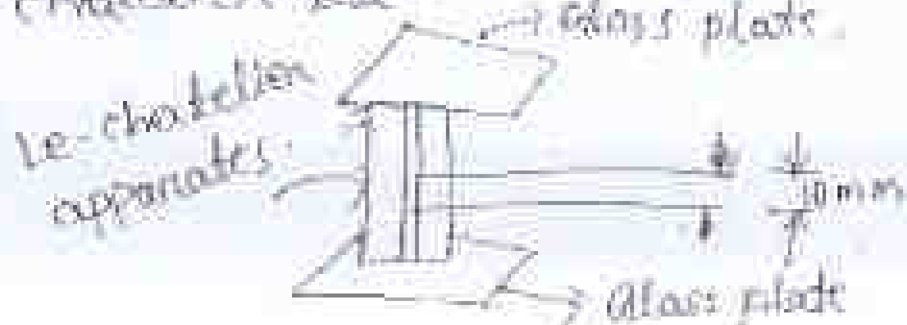
a) Limiting the MgO (Magnesia) content to less than 5.5%.

b) Fine grinding

c) through mixing

→ The chief test for soundness in done by Le-Chatelier in lab.

→ The expansion carried out in the manner described in IS 269-1989 should not be more than 10mm in Le-chatelier test.



(ii) Compressive strength :-

→ It is one of the important properties of cement.
→ The strength test is generally carried out in tension on samples.
→ To measure the strength of concrete crushing test and compressive strength test should be done.
→ These are conduct on standardised aggregates & under carefully controlled conditions and then there give a good indication on strength quality of cement.
→ cement mortar cubes (1:3) having an area of 5000mm² are prepared and tested in compression testing machine.
→ For ordinary portland cement the value of compressive strength for 3 days and 7 days should not exceed 16mpa and 22mpa.
→ The compressive strength test should be done in 3 days, 7 days and 28 days by using either universal testing machine (or) compressive test machine.
→ The grade that are used for making the concrete should be mentioned in IS 650:1991 and IS 456:2000.

Standard sand:-

A particular variety of sand available at Ennore in Tamil Nadu is used as standard sand which closely resembles the Leighton Buzzard sand (the British standard sand) in its properties.

The imported Leighton sand has been replaced by Ennore sand. The standard sand has following properties.

a) The standard sand shall be of quartz, of light gray or whitish variety and shall be free from silt.

b) The sand - grains shall be angular with space approximating to spherical forms.

c) The sand shall pass through IS:850 - μm sieve and not more than 10 percent shall pass through IS:600 - μm sieve.

d) It shall be free from organic impurities.

5. Heat of hydration:-

-> The silicates and aluminates of cement react with water to form a binding medium, which solidifies into a hardened mass.

-> This reaction is termed hydration, which is exothermic with approximately 120 cal/g heat being liberated. In the interior of mass concrete constructions like dams etc, the temperature can be as high as 50°C above the initial temperature of concrete mass at the time of placing the concrete.

-> This high temperature is found to persist for a prolonged period. At the same time, the exterior of the concrete mass losses some heat so that a steep temperature gradient may be established, and during the subsequent cooling of the interior, severe cracking may occur.

→ On the other hand, the heat of hydration may be advantageous in preventing the freezing of water in the capillaries of freshly placed concrete in cold weather.

→ The heat of hydration is defined as the quantity of heat, in calories per gram of hydrated cement liberated on complete hydration at a given temperature. ~~The different com~~

→ The different cement compounds hydrate at different rates and liberate different quantities of heats. On adding water to cement, a rapid heat of evolution lasting for few minutes is due to reaction of aluminates.

→ However, this initial heat evolution ceases quickly as solubility of aluminates is restrained by $CaSO_4$.

→ The total heat generated in the complete hydration process will depend upon the relative quantities of major compounds of cement.

→ A normal cement generally produces approximately 90 cal/g of heat in 7 days and go to 100 cal/g in 28 days.

→ It is determined by measuring the quantities of heat liberated by unhydrated and hydrated cements in a mixture of nitric and hydrofluoric acids; the difference between the two values represents the heat of hydration.

→ The heat of hydration of low-heat Portland cement should not be more than 65 and 75 cal/g of 7 and 28 days respectively.

→ The heat of hydration increase with

place.

→ For ordinary Portland cement (OPC) it varies from 37 cal/g at 5°C to 80 cal/g at 40°C. For common types of Portland cements, about 50 percent of the total heat is liberated between 1 and 3 days, about 75 percent in 7 days and 83 to 91 percent in six months.

→ By restricting the quantities of compounds C_3A and C_3S in cement, the high rate of heat liberation increases with the fineness of cement but the total amount of heat liberated is unaffected by the fineness.

6- Specific gravity:-

→ The specific gravity of Portland cement is generally about but that of cement manufactured from materials other than limestone and clay, the value may vary → Specific gravity is not an indication of the quality of cement. → It is used in calculation of mix proportions.

→ Oxide Composition of ordinary Portland cement:-

Oxide	Percentage	Average
(1) Lime (CaO)	60-75	63
(2) Silica (SiO_2)	17-25	20
(3) Alumina (Al_2O_3)	3.5-9	6.3
(4) Iron oxide (Fe_2O_3)	0.5-6	3.3

oxide (5) Magnesia (MgO)	0.5 - 4	2.4
(6) Sulphur trioxide (SO_3)	1 - 2	1.5
(7) Alkali that is soda/ Potash	0.5 - 1.3	1.0

* Types of cement :-

→ By using additives, changing the chemical composition of the portland cement by varying the percentage of four compounds that are present in the cement it is possible to obtain various type of cement.

→ A gradual increase of C_3S content and fineness has enabled general purpose of portland cement to develop very high strength at early ages.

→ Following are the main types of portland cement:-

(1) Ordinary portland cement OPC.
(2) Non- opc cement.

* General purpose of portland cement:-

The commonly used Portland cement in India is known as 33- grade (IS : 269 - 1989), 43 - grade (IS : 8112 - 1989) and 53 - grade (IS : 12269 - 1987) having 28 days mean compressive strength exceeding 33 MP

43 Mpa and 53 Mpa, respectively.

→ All the three grades of ordinary Portland cement are produced from the same materials as explained earlier.

→ The higher strengths are achieved by increasing the tricalcium silicate (C_3S) content and also by finer grinding of the clinker.

→ The fineness of 53 grade cement obtained by Blaine's air permeability test is specified to be of the order of 350000 mm²/g.

→ The requirements of the initial and final setting times are same as that of conventional opc.

→ The conventional opc, i.e 33 grade cement has virtually disappeared and has been displaced by high strength 43 grade cement. The minimum compressive strengths of the 43 grade cement are 23 Mpa and 33 Mpa at the end of three days and seven days, respectively.

→ The use of this cement was originally restricted to the production of railway sleepers and generally referred to as sleeper cement.

→ The railway specifications require that the initial setting time should not be less than 90 minutes.

→ At higher water cement ratios, the concrete produced with high-strength cement has about 80 percent higher strength and at lower cement ratios, it has 40 percent higher strength than that of concrete using 33-grade OPC.

→ The cost of high-strength Portland cement is only marginally higher than the OPC.

→ The use of this cement in the usual 1:2:4 nominal mix, with a water-cement ratio of 0.60 to 0.65 can easily yield M25 concrete.

→ Its composition and properties are government by IS: 8112-1989. Greater fineness of 43 and 53 grade cements increase workability due to reduction of friction between aggregates.

→ Moreover due to shorter setting time and faster development of strength, the stripping time is shorter.

→ Although cement of grades 43 and 53 are desirable for economical design of high-grade concrete but they can also be used for lower grade concretes. However, to make high-strength concrete a high-performance concrete, will require extremely careful batching, mixing, transportation, placing, compaction and curing.

IS: 10262-1982 has classified of OPC grade-wise from A to F depending upon the 28 days compressive strengths as A (32.5 - 37.5 Mpa), B (37.5 - 42.5 Mpa), C (42.5 - 47.5 Mpa), D (47.5 - 52.5 Mpa), E (52.5 - 57.5 Mpa), F (57.5 - 62.5 Mpa). Accordingly, the 33, 43 and 53 grades of cement correspond to categories A, C and E, respectively.

→ However, most of the 43-grade cements available in the market generally fall in the category E and the 53 grade cements available are generally in the category F or above.

→ The actual strength of cement must be ascertained either from the manufacturer or through laboratory tests before it is used in concrete mix design to get the maximum benefit of the additional strength and superior quality.

Special-purpose cements :-

The special-purpose cements are manufactured for the specific performance requirements. The frequently used ones are the following.

1- OPC-based cements.

2- Non-OPC cements.

These cements have some further classifications, which are described below.

OPC-Based Cements

1- Rapid-hardening Portland cement :-

→ This cement is similar to OPC but with higher C_3S content and finer grinding.

→ A higher fineness of cement particles provides greater surface area (not less than 325000 mm²/g) for action with water.

→ It gains strength more quickly than OPC, though the final strength is only slightly higher.

The one-day strength of this cement is equal to the three-day strength of 33-grade OPC with the same water-cement ratio.

→ This cement is used where a rapid strength development is required. The rapid gain of strength is used where a rapid strength development is required.

→ The rapid gain of strength is accompanied by a higher rate of heat development during the hydration of cement.

→ This may have advantages in cold weather concreting but a higher concrete temperature may lead to cracking due to subsequent thermal contraction, and hence should not be used in mass concreting of thick structural sections.

→ The composition, fineness and other properties are governed by IS: 8041-1990. It is only about 10 percent costlier than OPC. It is recommended for prefabricated concrete constructions, road-repairs and in applications requiring early stripping of forms.

2- Low-heat Portland cement:-

→ This cement is less reactive than OPC and is obtained by increasing the proportion of C_2S and reducing C_3S and C_3A.

→ This reduction in the content of more rapidly hydrating compounds C_3S and C_3A results in a slow development of strength but the ultimate strength is the same.

→ In any case, to ensure a sufficient rate of development of strength, the specific surface of cement must not be less than 320000 mm²/g.

→ The initial setting time is greater than OPC.

→ The properties and composition are governed by IS: 12600-1989.

→ This cement is recommended for the use in mass concrete construction such as where temperature rise by heat of hydration can become excessive.

3 - Sulfate-resisting cement:-

→ A portland cement with low C_3A (less than five percent) and C_4AF contents is very effective against sulfate attack. Such a cement having high silicate content is called sulfate-resisting cement.

→ The content of tetra-aluminoferrite C_4AF in OPC varies between 6 to 12 percent.

→ As it is not feasible to reduce the Al_2O_3 content of raw material, Fe_2O_3 is added to the raw materials mixture to increase C_4AF content at the expense of C_3A.

→ IS: 456-2000 limits the total content of C_4AF and C_3A such that $2C_3A + C_4AF$ shall not exceed 25 percent. Such a cement with low C_3A content is effective against sulfate attack whereas the ordinary Portland cement is susceptible to attack of sulfates in solution which permeate in the hardened concrete and react with free $Ca(OH)_2$, hydrate of calcium aluminate and even hydrated silicates to form calcium sulfoaluminate having a volume of approximately 227 percent of the volume of original alumina.

→ This expansion within the hardened structure of cement paste results in cracks and subsequent disruption.-

→ This phenomenon is called sulfate attack, which is greatly accelerated if accompanied by an alternate wetting and drying as in the case of marine environment.

→ The use of sulfate resisting cement is recommended for concretes to be used in the marine environment, foundations in chemically aggressive soils, for pipes to be buried in marshy regions or sulfate bearing soils, and construction of sewage treatment plants.

(4) Masonry cement:-

→ This cement is manufactured by intimately grinding a mixture of OPC clinker and gypsum with mineral additives (pozzolanas) or inert (non-pozzolanic) materials such as limestone, dolomite, carbonated slag etc. and air-entraining agents in suitable proportions generally to a fineness greater than that of OPC.

→ Masonry cement conforming to the standard requirement can be produced by intergrinding 2 parts of Portland cement clinker, 3 parts of fly ash and 5 parts of granulated blast furnace slag or 1 part of Portland cement clinker, 2 parts of fly ash and 2 parts of hydrated lime with suitable quantity of gypsum and an air-entraining admixture.

10. Masonry cement mortar is considered superior to lime mortar, lime-cement mortar and cement mortar.

→ It combines the desirable properties of cement mortar relating to strength and setting, and lime mortar relating to workability and water retention.

→ Thus a masonry cement produces a smooth, plastic, cohesive and strong, yet workable mortar.

→ The cracks due to shrinkage and temperature movement are considerably reduced. Its composition and properties are governed by IS:3466-1988.

→ The physical requirements of the masonry cement are:

a) Fineness

Residue on 45-micron sieve, max : 15 percent

b) Setting times

(i) Initial setting time, min 90 minutes

(ii) Final setting time, max 24 hours

c) Soundness

(i) Le-chatelier expansion, max 10 mm

(ii) Autoclave expansion, max 01 percent.

The following properties are measured on the mortar composed of one part of masonry cement and three parts of standard sand by volume:-

d) Compressive strength

(i) at 7 days, min 2.5 Mpa

(ii) at 28 days, min 5.0 Mpa

e) Air content, min 6 percent

→ Water - retention

Flow after suction as compared to the original flow, min 80 percent

Waterproof Portland cement :-

→ Waterproof cement is manufactured by adding a waterproofing substance to ordinary portland cement during mixing.

→ The common admixtures are calcium stearate, aluminium stearate and the gypsum treated with tannic acid.

6. White Portland cement :-

→ The process of manufacturing white cement is the same as of ordinary Portland cement but the amount of iron oxide, which is responsible for greyish colour, is limited to less than one percent.

→ This is achieved by careful selection of raw materials and often by the use of refined furnace oil (RFO) or gas fuel in place of pulverized coal in the kiln.

→ The suitable raw materials are chalk and high purity limestones having 95 percent $CaCO_3$ and less than 0.1 percent iron oxide contents, and white clays.

→ Its composition and properties are governed by IS:8042-1989. Generally white cement is ground finer than the gray cement.

7- Colored portland cement:-

→ These are basically Portland cements to which pigments are added in quantities up to 10 percent during the process of grinding the cement clinker.

→ A good pigment should be permanent, i.e., colour should be durable under exposure to light and weather, and chemically inert when mixed with cement. For lighter colours, white cement has to be used as basis.

8- Hydrophobic cement:-

→ This type of cement is obtained by adding water repellant film forming substance like stearic acid, boric acid, oleic acid and pentachlorophenol to OPC during grinding of cement clinker.

→ These acids form a film around the cement particles which prevent the entry of atmospheric moisture, and the film breaks down when the concrete is mixed, and then the normal hydration takes place.

→ The film forming materials also entrain certain amount of air in the body of concrete which improves its workability.

→ It composition and properties are governed by IS: 8043-1991.

→ This cement is useful for the places having high humidity, poor transportation system and perforce storage for long time. In such situations, OPC gets deteriorated and loses strength part of its strength.

→ The physical and chemical requirements for some of the commonly used cements are summarized in

9. Air-entraining cement:-

→ This cement is manufactured by mixing small quantity of air-entraining agent like alkali salts of wood resins synthetic detergents of alkyl aryl sulfonate type and calcium lignosulfonate with ordinary Portland cement.

→ These agents in powder or in liquid forms are added to the extent of 0.025 to 0.100 percent by weight of OPC cement clinker at the time of grinding.

→ At the time of mixing, these cements produce tiny, discrete non-coalescing air bubbles in the concrete mass which enhances workability and reduces tendency to segregation and bleeding.

10. Expansive cement:-

→ Cement which does not shrink while hardening and thereafter, but expands slightly with time is called expansive cement.

→ This cement does not suffer any overall change in volume on drying. Expansive cement is obtained by mixing about 8 to 20 parts of the sulfoaluminate clinker with 100 parts of the OPC and 15 parts of the stabilizer.

→ In one type of expansive cement called shrinkage compensating cement, the restraint to the expansion cement called shrinkage compensating cement, the restraint to the expansion induces compressive stress which approximately offsets the tensile stress induced by shrinkage.

→ In another type called self stressing cement, the concrete induces significant compressive stresses after the occurrence of drying shrinkage.

→ In addition to neutralizing the shrinkage they provide prestressing effect in the tensile zone of a flexural member.

→ This cement is commonly used for grouting anchor bolts or grouting machine foundations or prestressed concrete ducts wherein drying shrinkage may otherwise defeat the purpose of grout.

11 Oil-well cement :-

→ The annular space between steel casting and sedimentary rock foundation through which oil well has been drilled. is sealed off by cement slurry to prevent escape of oil or gas.

→ The cement slurry also seals off any other fissure or cavities in the rock layer. For this purpose cement slurry has to be pumped down to points located in the annulus around the casting at considerable depth where prevailing temperature may be as high as 350°C under pressure upto 150 Mpa.

→ The slurry used for this purpose must remain mobile to be able to flow under these condition for periods up to several hours and then harden hardly rapidly to give sufficient strength to support the casting.

It may also have to resist corrosive conditions from sulfur gases and water containing dissolved salts.

The type of cement suitable for above conditions is called oil-well cement.

→ The cement produced by inter-grinding Portland cement clinker, fly ash, gypsum and certain admixture (retarders) in suitable proportions has been found to conform to the requirements of an oil well cement.

→ These retarders prevent quick setting and retain slurry in mobile condition to facilitate penetration to all facilitate penetration to all fissures and cavities.

→ The composition and properties are governed by IS: 8229-1986.

Very high strength cements:—

The cements of this category can be obtained by improving particle packing density and microstructure of cement paste as follows.

1. Removing entrapped air:

→ In the conventionally mixed cement paste relatively large voids or defects are usually present due to entrapped air which limit the strength.

→ In one of the systems, water soluble polymer is used as a rheological aid to permit cement to be mixed with a very small amount of water and at final processing stage entrapped air is removed by application of modest pressure of 5 MPa.

→ This process has resulted in a strength of 300 MPa for calcium aluminate system and 150 MPa for OPC.
→ This system is called macro-defect free cement.

2. Providing densely packed system :—

→ OPC and ultra fine silica fume (5 to 20 percent) are mixed to obtain a densified system containing homogeneously arranged particles.
→ A compressive strength of 270 MPa has been obtained with silica fume substituted paste.

3. Achieving densification with warm pressing :—

→ By the method of warm pressing i.e., applying heat and pressure simultaneously to cement paste results in reduction of porosity and generation of very homogeneous fine microstructure with small porosity.
→ By warm pressing of mixture of Portland and calcium cements has resulted in compressive strength of 650 MPa.

Non-OPC cements :—

1. High-alumina cement :—

→ This cement is basically different from OPC and concrete made with it has properties different from OPC concrete.
→ High-alumina cement (HAC) is very reactive and produces a very high early strength.
→ About 80 percent of the ultimate strength is developed at the age of 24 hours and even at six to eight hours.

High-alumina cement has an initial setting time of about four hours and the final setting time of about five hours. Generally no additives are added to alumina cement.

For the same water cement ratio, the alumina cement is more workable than Portland cement.

The strength is adversely affected by rise in temperature. HAC is extremely resistant to chemical attack and is suitable for under sea water applications.

→ The raw materials used for the manufacture are limestone or chalk and bauxite which are crushed into lumps not exceeding 100 mm.

→ These raw materials with appropriate proportion of coke are charged into the furnace which is fired with pulverized coal or oil.

→ The fusion takes place at temperature about 1600°C.

→ The solidified material is fragmented and then ground to a fineness of 250000 - 320000 mm^2/g

→ The very dark grey powder is passed through magnetic separators to remove metallic iron. The alumina cement is considerably more expensive.

→ The pozzolana additives are not useful in concrete made with HAC because it does not produce calcium hydroxide that could react with pozzolanas.

→ Its composition and properties are governed by IS: 6452-1989. The approximate chemical oxide composition is as follows.

Alumina (Al_2O_3) 39 percent
Ferric oxide (Fe_2O_3) 10 percent
Lime (CaO) 38 percent
Ferrous oxide (FeO) 4 percent
Silica (SiO_2) 6 percent

→ During hydration of HAC initially monocalcium aluminate decahydrate (CAH_{10}), dicalcium aluminate octahydrate (C_2AH_8) and alumina gel (AH_3) are forming. However, these compounds of hydration are metastable and at normal temperature convert gradually to a more stable tricalcium aluminate hexahydrate (C_3AH_6).

→ This conversion is accompanied by a loss in strength and change in crystal form from hexagonal to cubical shape resulting in a increase in the porosity.

→ The increase in porosity enhances its vulnerability to chemical attack.

→ The rate of conversion increase with the rise in temperature.

→ The hydration and conversion process can be symbolically

$$3CAH_{10} \rightarrow C_3AH_6 + 2AH_3 + 18H$$

→ High alumina cement concrete loses considerably strength when subjected to humid condition and high temperature, undergoes insignificant conversion and has significant residual strength.

→ A completely degraded alumina cement has very high resistance to dry heat.

[illegible] made using [illegible] cement [illegible] crushed firebricks as aggregate can withstand temperatures up to 1350°C.

→ A refractory concrete for withstanding temperature up to 1600°C may be produced by using aggregates such as dead-burnt magnesite, carborundum, sillimanite etc. Since high alumina cement is slow setting but rapid hardening certain proportions of OPC may be added to reduce setting time.

→ Lithium salts have been effectively used as accelerator in high alumina cement to obtain high early strength cement.

→ This has resulted in strength as high as 4 MPa in one hour, 25 MPa in three hours time and 51 MPa in 24 hours time.

2. Magnesium phosphate cement:—

→ A very high early strength mortar and concrete developed by CRRI, consists of a pre-packed mixture of dead-burnt magnesite and fine aggregate mixed with phosphate.

→ It sets rapidly and yields durable high strength cement mortar.

→ The dead-burnt magnesite is obtained by calcining $MgCO_3$ at or above 1500°C and grinding the product to fineness of 300000 - 350000 mm²/g (Blaine).

→ The ground dead-burnt magnesite is mixed with commercially available crystalline mono ammonium phosphate after grinding it into a fine powder passing 600 μm sieve and other ingredients like sodium tri-polyphosphate in the form of fine powder, di-sodium tetra borate (borax), fine aggregate (crushed dolomite sand) and water, mixed for one minute.

→ After application in repair of road and subsequent air curing the traffic can be opened in a short period of about four to five hours.

* General purpose of portland cement:-

Note:-

① Grade 33:-

→ It is high in workability compared to other grades.

→ It is used mostly in plaster, masonry mortar.

Fineness = 300 kg/m2

Cube strength 3 days = 16 N/mm2

7 days = 22 N/mm2

28 days = 33 N/mm2

2- Grade -43:-

→ It is generally used for construction of reinforced concrete (R.C.C)

→ Also used for mixed concrete, precast concrete.

→ It has good working capacity.

Fineness = 225 Kg/m2

Cube strength 3 days = 23 N/mm2

7 days = 33 N/mm2

28 days = 43 N/mm2

3 Grade 53:-

→ It is used for construction of precast concrete.

→ Construction of factories, buildings, concrete design in railways.

fine ness = 225 kg/m2

Cube strength

3 days = 27 N/mm2

7 days = 37 N/mm2

28 days = 53 N/mm2

Note:-

1) For 33 Grade → IS 269
2) For 43 Grade → IS 8112
3) For 53 grade → IS 12269
4) 53 grade cement releases heat of hydration at a much faster rate compared to the 33 & 43 cement.

Chapter-3 Aggregates

Introduction:-

- Aggregates are generally cheaper than cement and impart greater volume stability and durability to conc
- The aggregates is used primarily for the purpose of providing bulk to the concrete. To increase the density of the resulting mix, the aggregate is frequently used in two or more sizes.
- The most important function of the fine aggregate assist in producing workability and uniformity in mixture.
- The fine aggregate also assist the cement paste to hold the coarse aggregate particles in suspension.
- This action promotes plasticity in the mixture and prevents the possible segregation of paste and coarse aggregate, particularly when it is necessary to transport the concrete some distance from the mixing plant to the point of placement.
- The aggregate provide about 75 percent of the body of the concrete and hence its influence is extremely important.
- They should be therefore meet certain requirement if the concrete is to be workable, strong, durable and economical.
- The aggregate must be of proper shape (either rounded or approximately cubical), clean, hard, strong and well graded.
- It should posses chemical stability and, in many cases exhibit abrasion resistance and resistance to freezing and thawing.

CLASSIFICATION OF AGGREGATES

The classification of the aggregates is generally based on their geological origin, size, shape, unit weight, etc.

Classification According to Geological Origin :-

→ The aggregates are usually derived from natural sources and may have been naturally reduced to size (e.g. gravel or shingle) or may have to be reduced by crushing.

→ The suitability of the locally available aggregates depends upon the geological history of the origin. Such an aggregate may further be divided into two categories, namely the natural aggregate and artificial aggregates.

Natural Aggregate :-

→ These aggregates are generally obtained from natural deposits of sand and gravel, or from quarries by cutting rocks.

→ The cheapest among them are the natural sand and gravel which have been reduced to their present size by natural agents such as water, wind and snow, etc.

→ The river deposits are the most common and are of good quality. The second most commonly used source of aggregates is the quarried rock which is reduced to size by crushing.

→ Crushed aggregate are made by breaking rocks into requisite graded particles by blasting, crushing and screening, etc. From the petrological standpoint, the natural in the mix in appropriate proportions.

- The particle size distribution is called the grading of the aggregate. According to size the aggregate is classified as: fine aggregate, coarse aggregate and all-in-aggregate.

Fine Aggregate:-

- It is aggregate most of which passes through 4.75 mm IS sieve and contains only that much coarser material as is permitted by the specification.
- Sand is generally considered to have a lower size limit of about 0.07 mm.
- Material between 0.06 mm and 0.002 mm is classified as silt, and still smaller particles are called clay.
- The soft deposit consisting of sand, silt and clay in about equal proportion is termed loam.
- The fine aggregate may be one of the following types-

1. Natural sand i.e., the fine aggregate resulting from natural disintegration of rock and / or that which has been deposited by stream and glacial agencies.
2. Crushed stone sand i.e., the fine aggregate produced by stream and gla
3. Crushed gravel sand, i.e., the fine aggregate produced by crushing natural gravel.

- According to size, the fine aggregate may be classified as coarse, medium and fine sands.
- Depending upon the particles size distribution, IS:383-1970 has divided the fine aggregate

into four grading zones.

→ The coarse aggregate may be one of the following types:-

Coarse Aggregate:-

→ The aggregates most of which are retained on the 4.75 mm IS sieve and contain only that much of fine material as is permitted by the specifications are termed coarse aggregates.

→ The coarse aggregate may be one of the following types

1. Crushed gravel or stone obtained by the crushing of gravel or hard stone.
2. Uncrushed gravel or stone resulting from the natural disintegration of rock
3. Partially crushed gravel or stone obtained as a product of the blending of the above two types.

→ The graded coarse aggregate is described by its nominal size, i.e. 40mm, 20mm, 16mm, and 12.5 mm, etc.

→ For example, a graded aggregate of nominal size 12.5 mm means an aggregate most of which passes the 12.5 mm IS sieve.

→ Since the aggregates are formed due to natural disintegration of rocks or by the artificial crushing of rock or gravel, they derive many of their properties from the parent rocks.

→ These properties are chemical and mineral composition, petrographic description, specific gravity, hardness, strength, physical and chemical stability, pore structure, and colour.

→ Some other properties of the aggregates not possessed by the parent rocks are particle shape and size, surface texture, absorption etc.

→ All this properties may have a considerable effect on the quality of concrete in fresh and hardened states.

All in-aggregate:-

→ Sometimes combined aggregates are available in nature comprising different fractions of fine and coarse aggregates, which are known as all in aggregate.

→ In such cases, adjustments often become necessary to supplement the grading by addition of respective size fraction which may be deficient in the aggregate.

→ Like coarse aggregate, the all-in-aggregate is also described by its nominal size.

→ The all-in-aggregates are not generally used for making high quality concrete.

Single-size-aggregate:-

→ Aggregates comprising particles falling essentially within a narrow band of size fractions are called single-size aggregates.

→ For example: a 20mm single-size-aggregate means an aggregate most of which passes through a 20mm IS sieve and the major portion of which is retained in a 10mm IS sieve -

Classification According to shape:-

→ The particle shape of aggregates influence the properties of fresh concrete more than those of hardened concrete.

→ Depending upon the particle shape, the aggregate may be classified as rounded, irregular or partly rounded, angular or flaky.

Rounded Aggregate

→ The aggregate with rounded particles (River or seashore gravel) has minimum voids ranging from 32 to 33 percent.

→ It gives minimum ratio of surface area to the volume, thus requiring minimum cement paste to make good concrete.

→ The only disadvantage is that the interlocking between its particles is less and hence the development of the bond is poor, making it unsuitable for high strength concrete and pavements.

Irregular Aggregate

→ The aggregate having partly rounded particles (Pit sand and gravel) has higher percentage of voids ranging from 35 to 38.

→ It requires more cement paste for a given workability.

→ The interlocking between particles, though better than that obtained with the rounded aggregate, is inadequate for high strength

Angular Aggregate:-

- The aggregate with sharp, angular and rough particles (crushed rock) has a maximum percentage of voids ranging from 38 to 40.
- The interlocking between the particles is good thereby providing a good bond.
- The aggregate requires more cement paste to make workable concrete of high strength than that required by rounded particles.
- The angular aggregate is suitable for high strength concrete and pavements subjected to tension.

Flaky and Elongated Aggregates:-

- An aggregate is termed flaky when its least dimension (thickness) is less than three-fifth of its mean dimension.
- The mean dimension of the aggregate is the average of the sieve sizes through which the particles pass and are retained respectively.
- The particle is said to be elongated when its greatest dimension (length) is greater than nine-fifth of its mean dimension.
- The angularity of aggregate affects the workability and stability of the mix which depends on the interlocking of the particles.
- The elongated and flaky particles also adversely affect the durability of concrete as they tend to be oriented in one plane with water and air voids forming underneath.

-> The presence of these particles should be restricted to 10 to 15 per cent.
-> This requirement is particularly important for crushed fine aggregate, since the material made this way contains more flat and elongated particles.
-> The angularity of the aggregate can be estimated from the proportion of voids in a sample, compacted as prescribed in IS : 2386 (Part-1)-1963
-> The higher the angularity number, the more angular is the aggregate.
-> The elongation index of an aggregate is defined as the percentage by weight of particles present in it whose greatest dimension (length) is greater than nine-fifth of their mean dimension.
-> Whereas, the flakiness index is the percentage by weight of particles having least dimension (i.e. thickness) less than three-fifth of their mean dimension.
-> The surface texture of the aggregate depends on the hardness, grain size and pore-characteristics of the parent rocks, as well as the type and magnitude of the disintegrating forces.
-> Based on the surface characteristics, IS:383-1970 classifies the aggregates as glassy, smooth, granular, crystalline, honeycombed, porous etc.
-> The shape and surface texture of aggregate influence the workability of fresh concrete and the compressive strength of hardened concrete, particularly in high strength concrete

- The strength of concrete, especially the flexural strength, depends on the bond between the aggregate and cement paste.
- The bond is partly due to the inter-locking of the aggregate and paste.
- A rough surface results in a better bond.
- The bond is also affected by the physical and chemical properties, mineralogical and chemical composition, and the electrostatic condition of the particle surface, e.g. a chemical bond may exist in the case of a limestone aggregate.

Classification Based on unit weight :-

The aggregates can also be classified according to their unit weight as normal weight, heavy weight and lightweight aggregates.

Normal Aggregates :-

→ The commonly used aggregates, i.e. sand and gravels, crushed rocks such as granite, basalt, quartz, sandstone and limestone and brick ballast etc. which have specific gravities between 2.5 and 2.7 produce concrete unit weight ranging from 23 to 26 KN/m3 and crushing strength at 28 day between 15 to 40 MPa are termed normal - weight concrete.

→ The properties and the requirements of normal - weight aggregate will be discussed in detail in the succeeding sections.

Heavyweight or High Density Aggregates :-

→ Some heavy weight or high-density aggregates such as barytes (Sg: 4.0-4.6), ferro-phosphorus (Sg = 5.8-6.8), goethite (Sg: 3.4-3.7), haematite (Sg: 4.9-5.3), ilmenite (Sg: 4.0-4.6) limonite (Sg = 3.4-4.0), magnetite (Sg: 4.2-5.2), de-greased scrap iron and iron shots (Sg: 6.2-7.8) are used in the manufacture of heavy weight concrete which is more effective as a radiation shield.

→ Concretes having unit weight of about 30, 31, 35, 38, 40, 47 and 57 KN/m³ can be produced by using typical goethite, limonite baryte, magnetic, hematite, ferro-phosphorus and scrap iron respectively.

→ where high fixed-water content is desirable, serpentine (which has a slightly higher density than normal-density aggregate) or bauxite can be used.

→ The main draw back with these aggregates is that they are not suitably graded and hence it is difficult to have adequate workability without segregation.

→ In general, selection of an aggregate is determined by physical properties, availability and cost. High-density aggregates should be reasonably free of fine materials, oil and foreign substances that may affect either the bond of paste to aggregate particle or the hydration of cement.

→ For good workability, maximum density, and economy aggregates should be roughly cubical in shape and free of excessive flat or elongated particles.

Lightweight Aggregate :-

→ The lightweight aggregates having unit weight up to 12 kN/m3 are used to manufacture the structural concrete and masonry blocks for reduction of the self-weight of the structure.

→ These aggregates can be either natural such as diatomite, pumice, volcanic cinder etc or manufactured, such as bloating clay, sintered fly ash or foamed blast-furnace-slag.

→ In addition to reduction in the weight the concrete produced by using light weight aggregate provides better thermal insulation and improved fire resistance.

→ The main requirement of the lightweight aggregate is its low density. Some specifications limit the unit weight to 12 kN/m3 for fine aggregate and approximately 10 kN/m3 for coarse aggregates for the use in concrete. Because of high water absorption, the workable concrete mixes become stiff within a few minutes of mixing thus requiring the wetting of the aggregates before mixing in the mixer.

→ In the mixing operation, the required water and aggregate are usually premixed prior to the addition of cement.

→ Approximately, six liters of extra water per cubic meter of light weight aggregate concrete is needed to enhance to workability by 25mm

→ To produce satisfactory strength of concrete, the cement content may be 35 kg/m or more.

→ Due to the increased permeability and rapid carbonation of concrete, the cover to the reinforcement using lightweight aggregate in concrete should be increased

→ The other characteristics of concrete using lightweight aggregates are reduced workability due to rough surface texture, lower tensile strength, lower modulus of elasticity (50 to 75 percent of that of normal concrete) and higher creep and shrinkage.

Characteristics of aggregate :-

→ Characteristic of aggregate depends upon toughness, strength, hardness, particle size of aggregate.

→ Following are the properties of aggregate :-

1. Strength of aggregate :-

→ The strength of concrete cannot exceed that of the bulk of aggregate contained therein. Therefore so long as the strength of aggregate is of an order of magnitude stronger than that of the concrete with them, it is sufficient. However, in the case of high strength concretes subjecting to localized stress concentration leading to stresses higher than the overall strength of concrete, the strength of aggregate may become critical.

→ Generally three tests are prescribed for the determination of strength of aggregate, namely aggregate crushing value, aggregate impact value and 10 percent fines value. Of these, the

→ crushing value, aggregate impact value and 10 percent fines value. Of these, the crushing value test is more popular and the results are reproducible. However, the 10 percent fines from 12.5 mm to 10 mm particle is more reliable. IS: 383-1970 prescribes a 45 percent limit for the crushing value determined as per IS: 2386-1963 for the aggregate used for concrete

→ other than for wearing surfaces and 30 percent for concrete for wearing surfaces, such as runways, roads and pavements.

→ BS: 882-1965 prescribes a minimum value of 10 tonnes in the 10 percent fines test for aggregates to be used in wearing surfaces and five tonne when used in other concretes.

→ The other related mechanical properties of aggregate which are important especially when the aggregate is subjected to high wear are toughness and hardness.

- The toughness of aggregate is subjected to high wear are the resistance of the aggregate to failure by impact. determined In accordance with IS:2386 (Part IV)-1963. may be used instead of its crushing value.
- The aggregate impact value shall not exceed 45 per cent by weight for aggregate used for concrete other than those used for wearing surfaces and 30 per cent for concrete for wearing surfaces.
- The hardness of the aggregate defined as its resistance to wear obtained in terms of aggregate abrasion value is determined by using the Los Angeles machine as described in IS-2386 (Part-IV)-1963.
- The method combines the test for attrition and abrasion.
- A satisfactory aggregate should have an abrasion value of not more than 30 percent for aggregates used for wearing surfaces and 50 percent for aggregates used for non-wearing surface.
- The strength of an aggregate as measured by its resistance to freezing and thawing is an important characteristic for a concrete exposed to severe weather

→ The resistance to freezing and thawing related to its porosity, absorption, and structure. In a fully saturated aggregate there is not enough space available

~~→ The strength of an aggregate as measured by its resistance to~~

to accommodate the expansion due to freezing of water resulting in the failure of the particles.

→ An aggregate with higher modulus of elasticity.

→ The modulus of elasticity of aggregate also affects the magnitude of creep and shrinkage of concrete.

2→ Particle shape and texture :-

→ The physical characteristics such as shape of aggregates, sight texture and roughness influence the mobility (i.e. the frankly of fresh concrete and the workability) of fresh concrete and the bond between the aggregate and the mortar phase.

→ As described earlier, the aggregates are generally divided into four categories, namely ; rounded, irregular, angular and flaky.

→ The rounded aggregates are available in the form of river or seashore gravel which are fully waterworn or completely shaped by attrition, whereas

Irregular or partly rounded aggregate are available ~~in the form~~ of river partly shaped by attrition and have rounded edges.

→ The angular aggregate possessing well-defined edges formed at the intersection of roughly planar faces are obtained by crushing the rocks.

→ The angular aggregates obtained from laminated rocks having thickness smaller than the width and/or length are termed flaky.

→ The rounded aggregates require lesser amount of water and cement paste for a given workability.

→ The water content could be reduced by 5 to 10 percent and the sand content by three to five percent by the use of rounded aggregate.

→ On the other hand, the use of crushed aggregate may result in 10 to 20 percent higher compressive strength due to the development of stronger aggregate mortar bond.

→ This increase in strength may be up to 38 percent for the concrete having a water-cement ratio below 0.4.

→ The elongated and flaky particles having a high ratio of surface area to volume reduce the workability appreciably.

→ These particles tend to be oriented in one plane with water and air voids underneath.

- The flakiness index of coarse aggregate is generally limited to 25 percent.
- The surface texture is a measure of the smoothness or roughness of the aggregate.
- Based on the visual examination of the specimen, the surface texture may be classified as glassy, smooth, granular, rough crystalline, porous and honeycombed.
- The strength of the bond between aggregate and cement paste depends upon the surface texture.
- The bond is the development of mechanical anchorage and depend upon the surface roughness and surface porosity of the aggregate.
- An aggregate with a rough porous texture is preferred to one with a smooth surface ~~rough~~ as the former can increase the aggregate cement bond by 75 percent.
- The surface pores help in the development of good bond on account of suction of paste into these pores.
- This explains the fact that some aggregates which appear smooth still bond strongly than the one with rough surface texture.
- The shape and surface texture of fine aggregate govern its void content and this affect the water requirement of mix very heavily.

→ The use of crushed or manufactured with ~~requirement of mix significantly~~ proper shape, surface texture and grading has enabled production of highly workable mix with minimum void content.

3. Specific gravity:-

→ The specific gravity of an aggregate is defined as the ratio of the mass of solid in a given volume of sample to the mass of an equal volume of water at the same temperature. Since the aggregate generally contains voids, there are different types of specific gravities.

→ The absolute specific gravity refers to the volume of solid material excluding the voids and therefore is defined as the ratio of the mass of solid to the weight of an equal void-free volume of water at a stated temperature.

→ If the volume of aggregate included the voids, the ~~resulting~~ resulting specific gravity is called the apparent/bulk specific gravity.

→ As the aggregate generally contains both impermeable and capillary voids (voids between the particles), the apparent specific gravity refers to volume including impermeable voids only.

It is therefore the ratio of the mass of the aggregate dried in an oven at 100 to 110°C for 24 hours to the mass of the water occupying a volume equal to that of solids including impermeable voids or pores.

- The specific gravity most frequently and easily determined is based on the saturated surface dry condition of the aggregate because the water absorbed in the pores of the aggregate does not take part in the chemical reaction of the cement and can therefore be considered a part of the aggregate.
- This specific gravity is required for the calculation of the yield of concrete or of the quantity of aggregate required for a given volume concrete.
- The specific gravity of an aggregate gives valuable information on its quality and properties.
- It is seen that the higher the specific gravity is above or below that which is normally assigned to a particular type of aggregate, it may indicate that the shape and grading of the aggregate has changed.
- The specific gravity is determined as described in IS:2386 (Part-III)-1963. The specific gravity is given by

$$\text{specific gravity} = \frac{C}{A-B}$$

and

$$\text{Apparent specific gravity} = \frac{C}{C-B}$$

$$\text{Water absorption} = \left(\frac{A-C}{C}\right) \times 100 \text{ per cent}$$

Where A = mass of saturated surface dry

B = mass of saturated surface dry aggregate in water and

C = mass of oven dry aggregate in air

The average specific gravity of majority of natural aggregates lie between 2.5 and 3.0

4- Bulk density :-

→ The bulk density of an aggregate is defined as the mass of the material in a given volume and is expressed in kilograms / litre.

→ The bulk density of an aggregate depends on how densely the aggregate is packed in the measure.

→ The other factors affecting the bulk density are the particle shape, size, the grading of the aggregate and the moisture content.

→ The shape of the particles greatly affects the closeness of the packing that can be achived.

→ For a coarse aggregate of given specific gravity a higher bulk density indicates that there are fewer voids to be filled by sand and cement.

→ The bulk density of an aggregate can be used for judging the quality of aggregate by comparing it with normal density for that type of aggregate

→ It determines the type of concrete for which it may be used

→ The bulk density is also required for converting proportions by weight into the proportions by volume. The bulk density is determined as described in IS : 2386 (Part - III) - 1963

5- Voids :-

- The empty spaces between the aggregate [illegible] are termed voids.
- It is the difference between the gross [illegible] of aggregate mass and the volume occupied by the the particles alone.
- The void ratio of an aggregate can be calculated from the specific gravity and bulk density of aggregate mass as follows:

$$\text{Void ratio} = 1 - \frac{\text{Bulk density}}{\text{Apparent specific gravity}}$$

6- Porosity and absorption of aggregates :-

- Due to the presence of air bubbles which are entrapped in a rock during its formation or on account of the decomposition of certain constituent minerals by atmospheric action, minute holes or cavities are formed in it which are commonly known as pores.
- The pores in the aggregate vary in size over a wide range, the largest being large enough to be seen under a microscope or even with the naked eye.
- They are distributed through out the body of the material, some are wholly within the solid and the others are open to the surface of the particle.
- The porosity of some of the commonly used rocks varies from 0 to 20 percent. Since the aggregate constitute about 75 percent of the concrete, the porosity of aggregate contributes to the overall porosity of concrete.

- The permeability and absorption affect the bond between the aggregate and the cement paste, the resistance of concrete to freezing and thawing, chemical stability, resistance to abrasion and the specific gravity of the aggregate.
- The pores may become reservoirs of free moisture inside the aggregate.
- The percentage of water absorbed by an aggregate.
- The aggregate which is saturated with water but contains no surface free moisture is termed the saturated surface dry aggregate.
- The method for determining the water absorption of an aggregate is described in IS : 2386 (Part-III) - 1963.
- If the aggregate is previously dried in an oven at 105°C to a constant weight before being immersed in water for 24 hours, the absorption is referred to as an ovendry basis.
- On the other hand, the percentage of water absorbed by an air dried aggregate when immersed in water for 24 hours is termed absorption of aggregate (air dry basis).
- The knowledge of the absorption of an aggregate is important for concrete mix design calculations.

7- Moisture content of aggregat

→ The surface moisture expressed as a percentage of the weight of the saturated surface dry aggregate is termed as moisture content. since the absorption represents the water contained in the aggregate in the saturated surface dry condition and the moisture content is the water in excess of that, the total water content of a moist aggregate is equal to the sum of absorption and moisture content.

→ IS : 2386 (Part-III) - 1963 describes the method to determine the moisture content of concrete aggregate.

→ The determination of moisture content of an aggregate is necessary in order to determine the net water-cement ratio for a batch of concrete.

→ A high moisture content will increase the effective water-cement ratio to an appreciable extent and may make the concrete weak unless a suitable allowance is made. IS : 2386 (Part-III) - 1963 gives two methods for its determination.

→ The first method namely, the displacement method, gives the moisture content as a percentage by mass of the saturated surface dry sample whereas the second method namely the drying method will normally be the total moisture content due to free plus absorbed water.

→ The accuracy of the displacement method depends upon the accurate information of the specific gravity of the material in a saturated surface dry condition.

8 Bulking of fine aggregate :-

> The increase in the volume of given mass of fine aggregate caused by the presence of water is known as bulking.

> The bulking of fine aggregate is caused by the films of water which push the particles apart.

> The extent of bulking depends upon the percentage of moisture present in the sand and its fineness.

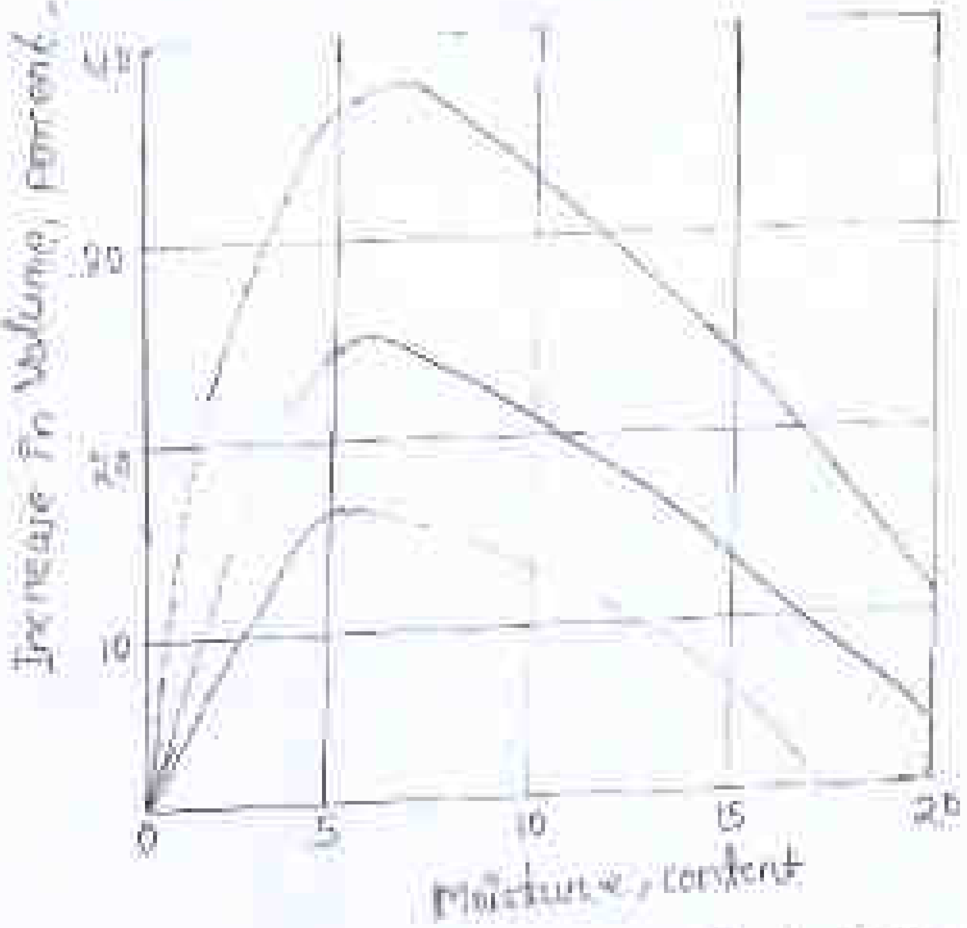
> It is seen that bulking increases gradually with the moisture content up to a certain point and then begins to decrease with further addition of water due to the merging of films until when the sand is inundated.

> At this stage, the bulking is practically nil. with ordinary sands the bulking usually varies between 15 and 30 percent.

> The typical graphs give the variation of percent bulking with moisture content.

> Finer sand bulks considerably more and the maximum bulking is obtained at a higher water content than the coarse sand.

> In extremely fine sand, the bulking may be of the order of 40 percent at a moisture content of 10 percent but such a sand is unsuitable for concrete. In the case of coarse aggregate, the increase.



Effect of moisture content on the bulking of sand

-> In volume is negligible due to the presence of free water as the thickness of the moisture film is very small as compared with particle size.

-> The percentage bulking is obtained in accordance with IS:2386 (Part-III)-1963.

-> If the sand is measured by volume and no allowance is made for bulking, the mix will be richer than that specified because for given mass, moist sand occupies a considerably larger volume than the same mass of the dry sand.

-> This results in a mix deficient in sand increasing the chances of the segregation and honey-combing of concrete.

→ The yield of concrete will also be reduced.
→ It is necessary, in such a case, to increase the measuring volume of the sand by the percentage bulking in order that the amount of sand put into concrete the amount intended for the nominal mix used (based on dry sand)
→ If no allowance is made for the bulking of sand a nominal concrete mix 1:2:4, for example, will correspond to 1:1.74:4 for a bulking of 15 percent.
→ An increase in bulking from 15 to 30 percent will result in an increase in the concrete strength by as much as 14 percent.
→ If no allowance is made for bulking the concrete strength may vary by as much as 25 percent.

Fineness Modulus

→ The fineness modulus is a numerical index of fineness, giving some idea of the mean size of the particles present in the entire body of the aggregate.
→ The determination of the fineness modulus consists in dividing a sample of aggregate into fractions of different sizes by sieving through a set of standard test sieves taken in order.
→ Each fraction contains particles between definite limits.
→ The limits being the opening sizes of standard test sieves above.
→ The material retained on each sieve after sieving represents the fraction of aggregate coarser than the sieve in question but finer than the sieve above.

→ The sum of the cumulative percentage retained on the sieves divided by 100 give the fineness modulus

→ The sieves that are to be used for the sieve analysis of the aggregate (coarse), fine or all-in aggregate for concrete as per IS:2386 (Part-1)-1963, are 80mm, 40mm, 20mm, 10mm, 4.75mm, 2.36mm, 1.18mm, 600 μm, 300 μm and 150 μm.

→ The fineness modulus can be regarded as a weight of average size of a sieve on which material is retained and the sieves being counted from the finest.

→ For example, a fineness modulus of 6.0 can be interpreted to mean that the sixth sieve, i.e., 4.75 mm is the average size.

→ The value of fineness modulus of higher for coarser aggregate.

→ For the aggregates commonly used, the fineness modulus of fine aggregate varies between 2.0 and 3.5 for coarse aggregate it varies between 5.5 and 8.0, and from 3.5 to 6.5 for all-in aggregate.

→ The object of finding fineness modulus is to grade the given aggregate for the most economical mix for the required strength and workability with minimum quantity of cement.

→ If the test aggregate gives higher fineness modulus, the mix will be harsh and if, on the other hand, gives a lower fineness modulus it will produce an uneconomical mix.

→ For workability, a coarser aggregate requires less water-cement ratio

→ The fineness modulus is also important for measuring the slight variations in the aggregate from the same source.

Grading and surface area of aggregate:-

→ The particle size distribution of an aggregate determined by sieve analysis is termed as grading of aggregate.

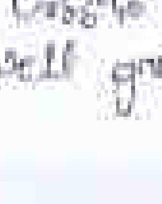
→ If all the particles of an aggregate are of uniform size the compacted mass containing more voids.

→ whereas particles of various sizes will give a mass containing lesser voids.

→ The particle size distribution of a mass of aggregate should be such that the smallest particles fill the voids between the larger particles.

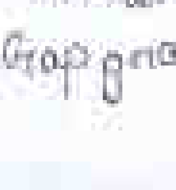
→ The proper grading of aggregate produces dense concrete and needs less quantity of fine aggregate and cements.

→ It is therefore essential that the coarse and fine aggregate be well graded to produce quality concrete.



Well graded

Poorly graded



Gap graded.

→ The grading of an aggregate is expressed in terms of percentage by weight retained on or passing through a series of sieves taken in order 80mm, 40mm, 20mm, 10mm, 4.75mm for coarse aggregate and 10mm, 4.75mm, 2.36mm, 1.18mm, 600 microns, 300 microns and 150 microns for fine aggregate.

→ The sieves are arranged in such an order that the square openings one half for each succeeding smaller size.

→ The curve showing the cumulative percentage of the material passing the sieves represented on the ordinate with the sieve openings to the logarithmic scale represented on the abscissa is termed the grading curve.

→ The grading curve indicates whether the grading of a given sample conforms to that specified or is too coarse or too fine, or deficient in a particular size.

1. In case the actual grading curve is lower than the specified grading curve the aggregate is coarser and segregation of mix might take place.
2. In case the actual grading curve lies well above the specified curve, the aggregate is finer and more water will be required, thus increasing the quality of cement for a constant water-cement ratio. Therefore, this is uneconomical.
3. If the actual grading curve is steeper than the specified, it indicates an excess of middle size particles and leads to harsh mix.
4. If the actual grading curve is flatter than the specified grading curve, the aggregate will be deficient in middle size particles.

→ The grading of the aggregate affects the workability which in turn, controls the water and cement requirements, segregation, and influences the placing and finishing of concrete.

→ These factors represent the important characteristics of fresh concrete and affect its properties in the hardened state.

→ The main factors governing the desired aggregate grading are: the surface area of aggregate, the relative volume occupied by the aggregate, the workability of the mix, and the tendency to segregate.

→ The surface area is affected by the maximum size of aggregates. If a sphere of diameter d is taken as representative of the shape of aggregates.

→ ~~If a sphere of diameter~~

→ The ratio of surface area to the volume is 6/d.

→ This ratio of surface of the particles to their volume is called specific surface.

→ The surface area will vary with the shape but is inversely proportional to the particle unit volume.

→ The aim must, therefore, be to have as large a maximum aggregate size as possible and to grade it down in such a way that the voids in the coarse aggregate are filled with the minimum amount of fine aggregate.

→ This arrangement, however, cannot be carried too far for an aggregate graded in this way would be too harsh and a slight excess of fine is necessary to prevent this.

The greatest contribution to this total surface area is made by the smaller size aggregate and therefore particular attention should be paid to the proportion and grading of fine aggregate.

→ The mortar consisting of fine aggregate and cement should be slightly in excess of that just required to fill the voids in the coarse aggregate.

→ Too coarse a fine aggregate results in harshness, bleeding and segregation and too fine an aggregate requires too large a water cement ratio for adequate workability.

→ The surface area of aggregate also influences the amount of mixing water and cement required.

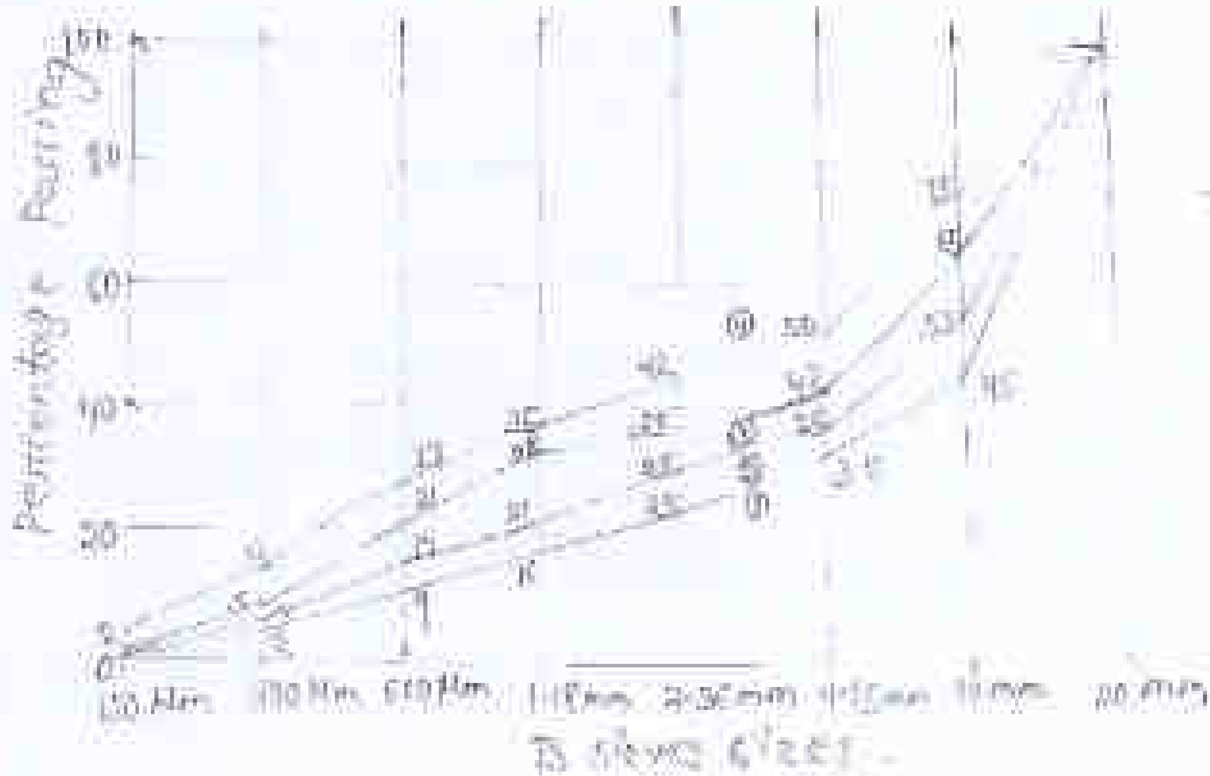
→ Generally, the water-cement ratio for adequate workability.

→ The surface area of aggregate also influences the amount of mixing water and cement required.

→ Generally, the water-cement ratio is fixed from strength considerations. However, the amount of cement paste should be sufficient to cover the surface of all the particles for proper workability and bond.

→ The drying shrinkage is less with a smaller amount of mixing water, and the temperature rise due to hydration and therefore cracking on subsequent cooling is less with the smaller proportion of cement in the mix.


Percentage Passing
IS sieve sizes


Percentage Passing
IS sieve sizes

Water

→ $\frac{W}{C}$ = 0.3 minimum $\frac{W}{C}$ → workability

$W = 0.323$
= m/L

→ grade of concrete, nature of aggregate, workability & durability.

→ Water is the most important & least expensive ingredient of concrete.

→ A part of mixing water is utilized in the hydration of cement to form the binding matrix which the ~~hydration of cement~~ inert aggregates are held in suspension until the matrix has hardened.

→ Generally cement requires about three-tenth of its weight of water for hydration.

→ Hence the minimum water-cement ratio required is 0.30.

→ The water cement ratio is influenced by the grade of concrete, nature & type of aggregate, the workability & durability.

→ If too much water is added to concrete, the excess water along with cement comes to the surface by capillary action.

→ This cement water mixture forms a thin layer of chalky material known as laitance.

→ The laitance prevents bond formation between successive layers of concrete & forms a plane of weakness.

→ Excess water may also leak through the joints of formwork & make the concrete honeycombed.

→ The smaller the percentage of water the stronger is the concrete.

* Quality of mixing water:-

-> The water used for mixing & curing of concrete should be free from injurious amounts of deleterious material.

-> The mixing & curing of water should not be inappropriate quality that causes concrete leading to dirtiness.

-> In case of doubt of suitability of water particular by in remote areas (or) when water is derived from sources not normally utilized for domestic purpose then water should be tested.

* Effects of impurities in water on properties of concrete:-

-> The strength & durability of concrete is reduced due to presence of impurities in the mixing water.

-> The effects are mainly expressed in terms of difference in the setting time of portland cement mixes containing proposed mixing water as compared to distilled water.

-> A difference in 28-days compressive strength up to 15% of control test is generally considered to be satisfactory measure of the quality of mixing water.

-> IS 456:2000 prescribes a difference in initial setting time of ± 30 minute with initial setting time not less than 30 time.

-> The effluents from sewage work, gas work & from paint, textile, sugar & fertilizer industry are harmful for concrete.

-> The test show that water containing excessive amount of dissolved salt - reduces compressive strength by 10 to 30 percent.

→ In addition water containing large quantities of chlorides tends to cause dampness surface efflorescence & increases the corrosion of reinforcing steel.

→ The effects of various impurities on properties of concrete are summarized below:-

A) Suspended Particles:-

* The presence of suspended particles of clay & silt in the mixing water upto 0.02% by weight of water does not affect the properties of concrete.

→ Even higher percentage can be tolerated so far as strength is concerned but other properties of concrete are affected.

→ IS 456:2000 allows 2000 mg/litre of suspended matter.

B) Miscellaneous Inorganic salts:-

* The presence of salts like manganese, tin, zinc, copper & lead in water causes reduction in the strength of concrete.

→ The zinc chloride retard the setting of concrete to such an extent that no strength available at 2/3 days.

→ The effect of lead nitrate is completely destructive.

→ Some other salts like sodium iodate, sodium phosphate, sodium arsenate & sodium borate reduce the initial strength of concrete to very low.

→ The carbonates of sodium & potassium may cause extremely rapid setting & reduce the concrete strength.

→ Presence of calcium chloride accelerates setting & hardening.

→ The quantity of calcium chloride is reducing to 1.5% by weight of cement.

CURING WATER :-

→ The use of water in curing the concrete is intended to penetrate the concrete.

→ If steps are taken to prevent loss of water from the concrete, no added water will be needed as a part of curing process except in the circumstances i.e. is when the water-cement ratio is less than 0.5 [illegible] when the concrete is produced using expansive cement.

→ Even at a water-cement ratio of 0.42, empty capillary pores exist, however, there is enough water in the mixture for hydration to proceed to completion, but it is necessary for the water to be uniformly distributed throughout the mass of concrete.

→ In structural members, there is inevitably some loss of water by evaporation from the surface.

→ Consequently hydration may effectively proceed in the interior of the member but near the surface, there is an inadequate amount of water in the capillaries so that penetration by curing water is highly desirable.

→ However, if the water used for curing is seawater, chloride ions enter the surface zone [illegible] from there move inwards by diffusion.

→ From the standpoint of durability, it is the area surface zone that is much more important than the concrete in the interior of the mass [illegible]

- the problems still at the surface or through attack progressing from the surface inwards.

- In the case of marine structures cast on land, but destined for immersion in the sea, the risk of exhibitions of seawater is high, unless thorough curing with fresh water has been done previously.
- The water which is satisfactory for mixing can also be used for curing it but should not produce any objectionable stain or unsightly deposit on the surface.
- Iron and organic matter in the water are chiefly responsible for staining or discolouration and especially when concrete is subjected to prolonged wetting, even a very low concentration of these can cause staining.
- According to IS : 456 - 2000, the presence of tannic acid or iron compounds in curing water is objectionable.
- It is generally recommended that the seawater should not be used as mixing water for hydraulic cement concrete work containing corrodible embedded ferrous metals, particularly in the tropics.
- However, under unavoidable circumstances it may be used for mixing and curing in plain concrete after due evaluation of possible disadvantages and consideration of the use of appropriate cement system.

Salts in seawater :-

- seawater generally contains 3.5 percent of dissolved salts.
- The chemical composition of seawater throughout the world is remarkably uniform and all the chloride is associated with sodium except for a very small

cement with potassium and all these sulfate is attack less with magnesium.

→ The approximate percentages of various ions relative to the salts in seawater are: chloride 55.2; sulphate 7.7; sodium 30.5; magnesium 3.7; calcium 1.2; potassium 1.1. However, the total amount of any ion varies widely.

→ For a given mass of seawater the ingress into the concrete of any given ion is proportional to the salinity of that seawater.

→ From the standpoint of chemical effects of seawater on plain or reinforced concrete it is the sulfate ions which is problematic, hence the need for sulfate-resisting cement.

→ However, the [illegible] need is greatly reduced by employing concrete of low water cement ratio.

→ The salts present in seawater reduce the ultimate strength of concrete.
→ The reduction in strength of concrete may be of the order of 15 to 20 percent.
→ The major concern is the risk of corrosion of reinforcing steel due to chlorides.
→ In general the risk of corrosion of steel is more when the reinforced concrete member is exposed to wet and dry conditions than when it is continuously submerged under water.
→ The presence of chlorides usually is also responsible for efflorescence.
→ It is advantageous to use cement with as much C₃A as can be tolerated without causing sulfate attack in concrete containing metallic metal.

→ The more is the C3A in the cement, the more chloride ion will be intercepted by aluminate (precipitated as non-detrimental calcium chloroaluminate) taking longer for the ions to build up at the surface of the steel.

→ There are two sources for the presence of chloride ion in the concrete. The first is calcium chloride added as an accelerating admixture and the second one is the intentional use of seawater as mixing water.

→ For normal cements that are not highly sulfate-resisting, the use of CaCl2 reduces the sulfate-resistance, but not when appropriate sulfate-resisting cement is employed.

→ The use of CaCl2 as an accelerator can be permitted in cold weather with sulfate-resisting cement to the same limited extent as with ordinary cements.

→ However, the codes forbid the use of calcium chloride when sulfate-resisting cement is being used.

→ Under unavoidable circumstances, it may be used for plain concrete when it is constantly submerged in water.

Acids and Alkalies:-

→ The industrial waste water containing acids or alkalines is really unsuitable for concrete construction.

→ With reference to acidity, the water having pH value higher than 6 can be used.

→ However, the pH value may not be a satisfactory measure of the amount of acid

→ The effect of acidity in water is best judged on the basis of total acidity, the extent of which should satisfy the following requirement

→ The amount of 0.02 normal NaOH required to neutralize 100ml sample of water using phenolphthalein as indicator should not be more than 5ml.

→ This acidity is equivalent to 49 ppm of H_2SO_4 or 35 ppm of HCl.

__Algae:-__

→ Algae may be present in mixing water or on the surface of aggregate particles.

→ It combines with cement and reduces the bond between aggregates and cement paste.

→ The water containing algae has the effect of entraining large quantities of air in concrete and thus lowering the strength of concrete.

__Sugar:-__

→ If 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.

→ Small amounts of sugar up to 0.15 percent by weight of cement retard the setting of concrete and the early strength may be reduced whereas the 28 days strength may be improved.

→ When the quantity of sugar is increased to 0.20 percent by weight of cement, setting is accelerated.

→ When quantity is further increased, rapid setting may result and 28 days strength is reduced.

Oil contamination:-

→ Mineral oils not mixed with animal or vegetable oils have no adverse effect on the strength of concrete.

→ If the concentration of mineral oil is up to two percent by weight of cement, a significant increase in strength has been noticed. For a percentage of mineral oil (more than eight percent), the strength is slightly reduced.

→ The vegetable oils have detrimental effect on the strength of concrete particularly at later ages.

Admixture

- Admixture are the chemical compounds in concre other than hydraulic cement (opc), water, aggregate & mineral additive that are added to the concrete.
- Admixture is added to mix immediately before (or) during mixing to modify one (or) more of the specific properties of concrete.
- The use of admixture should offer an improvement not economically by adjusting the proportions of water, cement & aggregates/ should not be adversely affect the performance of the concrete.
- The admixture have formulated chemical composition & specific chemical action & are used to modify certain properties of concrete.
- They are primarily used to reduce the cost of concrete, to modify the performance of hardened concrete, to ensure the quality of concrete during mixing, transporting, placing, compacting & curing & to overcome certain emergencies during concreting operation.
- The properties that are commonly modified are setting time, workability, rate of hydration, strength etc.
- The effectiveness of an admixture depends on several factors including type & quantity of cement, water content, mixing time, slump, temperature of concrete & air.

Function of admixture:-

→ Following are the function of admixture-

(a) To accelerate the initial set of concrete i.e, to speed up the rate of hydration of development of strength at early ages.

b) To retard the initial set i.e to keep concrete workable for a longer time for placement.

(c) To enhance the workability.

d) To increase the durability of concrete i.e to enhance the resistance to special conditions of exposure

(e) To increase the resistance to chemical attack

(f) To reduce the heat of hydration.

(g) To increase the bond between new & old concrete surfaces

(h) To enchance the bond of concrete to the steel reinforcement.

(i) To increase the strength of concrete, by reducing the water content in concrete

(j) To reduce the segregation in concrete mix.

(k) To improve the penetration in concrete.

(l) To produce coloured concrete or coloured mortar surface.

(m) To produce concrete of fungicidal, germicidal & insecticidal properties.

* Classification of Admixture :-

General purpose

a) accelerating admixture
b) Retarding admixture
c) air - entraining
d) water - reducing

Speciality category

a) grouting admixture
b) air - detraining
c) gas - forming
d) corrosion inhibiting
e) shrinkage reducing
f) water (or) damp proofing & permeability reducing admixture
g) bonding admixture
h) concrete surface hardening admixture
i) coloring admixture (or) pigments
j) fungicidal, germicidal & insecticidal admixture

(A) Accelerating admixture :-

> An admixture is used to speed up the initial set of concrete is called an accelerator.

> these are added to concrete either
(i) to increase the rate of hydration of hydraulic cement, hence to increase the strength.
(or) (ii) to shorten the setting time.

> An increase in the rate of early strength development may help in

(i) earlier removal of forms.
(ii) Reduction of required period of curing.
(iii) Earlier placement of structure in service.

→ Accelerating admixtures are also used when the concrete is to be placed at low temperature.

→ The benefits of reduced time of setting may include:
(i) Early finishing of surface.
(ii) Reduction of pressure on forms or of period of time during which the forms are subjected to hydraulic pressure.
(iii) More effective against leaks due to hydraulic pressure.

→ With the availability of powerful accelerators, the underwater concreting, the basement waterproofing operations, the repair works of waterfront structures in the tidal zones become easy.

→ The general action of accelerators is to cause a more rapid dissolution of compounds of cement particularly tricalcium silicate in water & hence facilitate more rapid hydration of these compounds.

→ The most widely used accelerator is calcium chloride ($CaCl_2$).

→ $CaCl_2$ can generally be used 2 percent by mass of cement.

→ According to IS: 7861 (Part-II) — 1981 recommends a maximum of 1.5% of $CaCl_2$ or admixture in concrete.

$CaCl_2$ should not be used in concrete which will be subjected to alkali-aggregate reaction or exposed of soils or water containing sulphates in order to avoid the lowering of the resistance of concrete to sulphate attack.

→ The use of 2% of $CaCl_2$ by mass of cement can reduce the setting time by 1/3rd & raise the (1-7) days compressive strength by (3 to 8) MPa.

→ An increase of flexural strength of (40-90)% of one day & 4 to 12% at 28 days is obtained.

→ Large doses of $CaCl_2$ result in flash set of cement & it also increase the shrinkage.

→ The other commonly used accelerators are Na_2SO_4, $NaOH$, Na_2CO_3, KOH, K_2SO_4

Note :- NaOH & KOH + concrete → rapid hardening of concrete (Excess of both)

(B) Retarder admixture :-

→ The set retarding admixture slow down the initial set & initial rate of hydration of cement or prolong the plasticity of cement paste in concrete.

→ They are used primarily to offset the accelerating & damaging effect of high temperature & to keep concrete workable during its entire placing period which should be sufficiently long so that the succeeding lifts can be placed without the development of cold joints or discontinuous in a structural unit.

→ They are also used in grouting oil wells.

→ The retarding of hydration means that the cement slow its hydration uses some of the water could available to provide workability.

→ High temperature, low humidity & wind cause rapid evaporation of water from the mix during summer.

→ The drying of concrete leads to the cracking of the surface.

→ Retarders delay setting of cement either by forming a thin coating on the cement particles & thus slowing down their dissolution in & reaction with water (or) by increasing the inter-molecular distance of reacting silicates & aluminates from water molecules by forming certain compounds in the system.

→ Retarding admixture hold back the hydration process, leaving more water for workability & allowing concrete to be finished & protected before drying out.

→ Some of the retarding admixture also reduce the water requirement of the mixture making further reduction in water-cement ratio.

→ Retarders do not affect the final setting time & the compressive strength that is come out in 28 days.

→ The material used as water reducing & set controlling admixture generally called retarding plasticizers. Following are the groups include in this category.

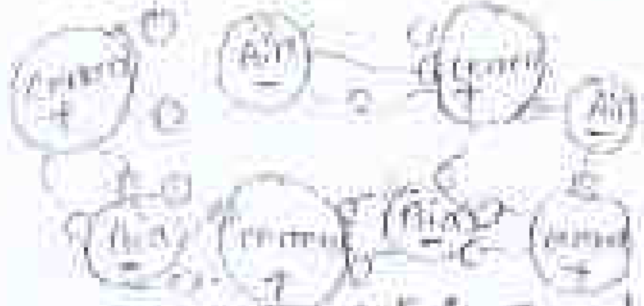
(i) Soluble carbohydrate derives :-

- Sugar
- Water soluble carbohydrate
- Starch
- Dextrine

(ii) Inorganic Retarder :-

- Zinc
- Lead
- Alkali - bicarbonates
- Calcium borate

C) Air - entraining admixture :-



→ Air entraining admixture help to incorporate a controlled amount of air, in the form of millions of minute bubbles distributed throughout the body of concrete during mixing, without significantly altering the setting (or) rate of hardening of concrete.

→ It is generally recognized that a proper amount of entrained air results in improved properties of plastic concrete like workability, easier placing & finishing, increased durability, better resistance to frost action & reduction in bleeding / segregation.

→ The entrained air bubbles ranging approximately from 0.05 to 0.25 mm diameter & spaced 0.10 mm apart reduce the capillary forces in concrete.

→ The air voids present in concrete are classified as entrained air & entrapped air :-

→ Entrained air is intentionally incorporated in the form of minute bubbles.

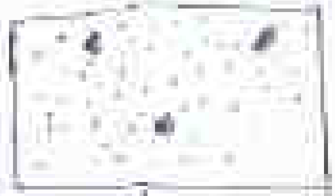
→ Whereas the entrapped air is in the form of voids ... in the concrete due to insufficient ...

compaction.

→ Entrapped air may be of any shape & size & non-uniformly distributed in the concrete.

→ Entrapped air size is large & range vary from 0.01 to 10mm & more.

Entraining concrete



Entrapped concrete.

→ Air entraining admixture increase the durability & plasticity, but there is decrease in strength of concrete.

→ This type of admixture create minute bubble in concrete which has flexibility due to which it has strong bond with cement, which increase its plasticity.

→ Compacting process is done during the construction of concrete for removing the air from concrete & after completion of concrete there is certain percentage of concrete is present & the water also evaporated from concrete due to temperature. which creates small voids in concrete & when the

→ concrete comes to the contract which atmospheric moisture content again those voids absorb those moisture & due to temperature again evaporation happend to concrete.

→ The above process is known as freezing (makes concrete hardened) & thawing process.

→ By adding air entraining admixture freezing & thawing process can be reduced & due to which durability is increased.

Air entraining admixture	→ ∝ strength
	→ ∝ durability, workability & plasticity

→ For each percent increase in air content the compressive strength reduces approximately 1.4 mpa.

→ With in the normal range of air content, the maximum reduction in compressive & flexural strength rarely exceeds 15 & 10 percent.

→ The reduction of water cement ratio & sand content made possible by air entrainment for the given workability.

→ The beneficial amount of entrained air depends upon the type & quantity of air-entraining agent, water cement ratio of the mix, type, grading & maximum size of aggregate & type of cement.

Maximum size of aggregate (mm)	Naturally entrained	Optimal total
(i) Sand-cement mortar	4.0	14 ± 2
(ii) 10	3.0	8 ± 1.5
(iii) 12.5	2.5	7.5 ± 1.5
(iv) 20	2.0	7.0 ± 1.5
(v) 25	1.5	6 ± 1.5
	[illegible]	4.5 ± 1.5

vii) 50	0·5	4·0 ± 1·0
viii) 70	0·3	3·5 ± 1·0
(ix) 150	0·2	3·0 ± 0·5

→ The minute bubble that are generated due to air entraining agents act like flexible ball bearing help in to increase the mobility of concrete by reducing the friction between the particles, i.e. they modify the properties of fresh concrete with regard to it's workability, avoid the segregation & bleeding due to improved cohesion, finishing quality of concrete.

Effect of permeability:-

→ Greater uniformity of air entrained concrete due to entrained air content, modified pore structure, reduced water channels due to reduction in bleeding are the some of reason for the improvement of its permeability.

Effect on chemical resistance:-

→ In view of the lower permeability & absorption the air entrained concrete has greater resistance for chemical attack than normal concrete.

→ It has been reported that air-entrainment reduces the alkali aggregate reaction.

Unit weight:-

→ For the same workability & strength the air entrained concrete contains approximately 5% less solid material, hence has lower density.

→ Usually, the desirable entraining air content in concrete is (3-6)%. Ex:- Vinsol resin

(c) Water Reducing Admixture :-

↓

Plasticizer

- ↓ Dispersion
  - 
  - Workability Required ↓ strength
- ↓ Retarding effect
  - setting time reduce
  - ↓ cement particle surface

→ When water is added to a concrete, mortar, plaster, the cement & other fines in the mix such as flyash, stone dust, silica fume flocculate (or) clump together.

→ The flocculated fines cause an increase in viscosity by entrapping a part of the water & by physically restricting the flow.

→ To reduce the viscosity to the desired level, it may be necessary to add more water.

→ Water is added upto a certain point, beyond which the intend plastic & hardened physical properties of the mixture are compromised.

→ To achive the desired workability & hardened physical properties of the mixture, it is necessary to add a water reduce to disperse (or) deflocculate the system & reduce the addition of water.

(iii)
(iv)
(v) 25
(vi) 40

→ The organic (or) combination of organic & inorganic substances to achieve these objectives are termed as plasticizing admixture

→ Water-reducing admixtures enable a given freshly concrete mix to have higher workability without increasing the water content which results in faster rate of concrete placement.

→ Benefits of water reduction in hardened state of concrete are increased strength, density, durability, volume stability, abrasion resistance, reduced permeability & cracking.

→ A good plasticizer is different from air entraining agents.

→ A good plasticizer does not entrain air more than (1 (or) 2) % fraction

Action of plasticizer :-

- Dispersion
- Retarding effect

(1) Dispersion :-

→ Portland cement, being in fine state will have a tendency to flocculate in wet concrete.

→ This flocculation entraps certain amount of water use in the mix and there by all the water is not freely available to fluidify the mix.

→ When plasticizers are added, they get adsorbed on the cement particles

→ The adsorption of charged polymer on the cement particles create repulsive forces between particles which overcome the attractive forces.

→ This repulsive force is known as zeta potenti which depends on the solid content and qualit of plasticizer.

→ The overall result is that the cement particles are deflocculated and dispersed.

→ When cement particles are deflocculated the water trapped inside the flocs gets released and becomes available to fluidify the mix.

→ More over, in the flocculated state there is inter-particle friction between particle and particle and floc and floc.

(ii) Retarding effect :-

a) Reduction in surface tension of water.

b) Lubricating film between cement particles.

c) Dispersion of cement grains releasing water trapped within cement flocs.

d.) Induced ele

Generally an admixture capable of reducing water requirements by more than five percent is classified as water reducer or plasticizer.

→ Depending upon the degree of water reduction, the water reducers are categorized as normal water reducer, mid range water reducer and high-range water reducer or superplasticizer.

→ The normal water reducer reduces water content by 5 to 10 percent. The mid-range water reducers reduce water content by about 10 to 15 percent and tend to be more stable over a wider range of temperature.

→ Mid-range water reducers provide more consistent setting times than normal water reducers. Higher water reductions, by incorporating large amounts of these admixtures, result in undesirable effects on setting, air content, segregation, bleeding and hardening.

→ A new class of water reducers, chemically different from the normal and mid-range water reducers and capable of reducing water content by about 20 to 40 percent has been developed.

→ The admixture belonging to this class are popularly known as high-range water reducers (HRWR) or superplasticizers. They can be added to a concrete mix having a low-to-normal slump and water-cement ratio to produce high-slump flowing concrete.

→ Flowing concrete is a highly fluid but workable cohesive concrete that can be placed homogeneously with little or no vibration or compaction.

→ The effect of superplasticizers lasts only 30 to 60 minutes, depending on its composition and dosage, and is followed by a rapid loss in workability. As a result of the slump loss, superplasticizers are usually added to concrete at the job site.

Mid-range water Reducer

The mid-range water-reducing admixtures can be categorized as

1- Derivatives of lignosulfonic acids and their salts (e.g. Ca, Na, NH_3 salts)

2 - Hydroxylated carboxylic acids and their salts.

3 - Modifications and derivatives of hydroxylated carboxylic acids and their salts.

4 - Processed carbohydrates.

→ The lignosulfonates and carboxylic acids derivatives and their salts are water reducing and set-retarding admixtures, and they are known to reduce setting times by two to four hours and water requirement by 8 to 15 percent.

→ The compressive strength at two to ~~three~~ ~~hours~~ ~~and~~ ~~or~~ on three days is usually equal to, or little higher than that of corresponding concrete without the admixture and the strength at 28 days or later may be 10 to 20 percent higher. These may be used with accelerating or retarding admixtures.

→ Calcium sulfate (gypsum), sugar and carbohydrates also retard the set.

→ The carbohydrate derivatives and calcium lignosulfonate are used in fractions of a percent by mass of the cement.

→ The dosage of hydroxylated carboxylic acid derivatives range from 0.1 to 0.2 percent by mass of cement.
→ These admixtures are more effective than ligno sulfonates in mixes of higher cement contents (say in excess of 350 kg/m3). They are fairly insensitive to variation in cement composition. On the other hand, modified lignosulfonates are more effective in concrete with relatively low-cement contents and dosage would vary from 0.1 to 0.3 percent for sodium
→ lignosulfonate and 0.3 to 0.5 percent for calcium lignosulfate.

High-range water Reducers or superplasticizers

→ These admixtures are principally surface reactive agents (surfactants). They confer negative charge on individual cement particles (and also its hydrated particles) such that they are kept in dispersed or suspended state due to inter-particle repulsion. Thus they confer high mobility to the particles.
→ superplasticizers enable the optimization of water content or water-cement ratio and workability. Both the functional effects - providing enhanced plastic and hardened physical properties - are achieved simultaneously by the use of superplasticizer.
the use of superplasticizer is cost effective.
→ An ideal superplasticizer which produces a cohesive low-viscosity rheology without and reliable dispersant which produces a cohesive low viscosity rheology without tendency to segregate, bleed and foam, with little interference with hydration, and compatible with different cement types and with

other commonly used chemical and mineral add
→ A simple way of utilizing the superplastic is to proportion the ingredient of the mixture to produce the required hardened physical properties and then and sufficient superplasticize to achieve required consistency or workability.

Speciality category Admixture:-

(i) Grouting admixture:-

→ Grouting has become on of the most important operations in civil

→ Grouting below the base peal (or) machine foundations grouting of foundation bolt holes in industrial structures, grouting of prestressed concrete ducts, grouting in anchoring and rock bolting systems, grouting of curtain wall, grouting of fissured rocks below dam foundations, grouting the body of the newly constructed dam itself, grouting of deteriorated concrete (or) face of the structure for strengthening and rehabilitation, grouting of oil walls are some of the few situations where grouting is extremely used

→ The grout material should have high early or ultimate strength, should be free flowing even at low water content, should develop good bond with previously set (or) hardened concrete, essentially it should be non-shrink in nature.

→ The grouting materials can be broadly classified into two categories one is free flow grout (or) ...

machine foundations, foundation bolts and fixing crane rails.

→ The second category of grout is meant for injection grouting to fill up small cracks and is normally accomplished under pressure.

→ Some retarders are especially useful in cement grout slurries particularly where grouting is prolonged (or) in the cases where the grout must be pumped for a considerable distance (or) where hot water, high temperature is encountered under ground.

→ Cement grouts containing pozzolanic materials are often used in cement paste and oil wells.

→ Admixtures are also used to prevent the rapid loss of water from cement paste.

→ Some of the grouting admixtures are gels, clays, pregelatinized starch, methyl cellulose.

2) Air-detraining Admixture:-

→ These materials are used to:-

(i) dissipate excess air (or) other gases.

(ii) Remove a part of entrained air from a concrete mixture.

→ Air detraining admixture is tributyl phosphate, dibutyl phthalate, water insoluble alcohols & silicons.

→ Mostly used air detraining admixture is tributyl phosphate.

B- Air - entraining Admixtures:-

3) Gas-forming Admixture:-

Concrete (or) mortar

↓

Hydroxide

↓

Minute bubble of hydrogen

↓

0.1 to 1mm.

→ These admixture when added to mortar (or) cement mixture react chemically with hydroxide present in the cement & form minute bubble of hydrogen gas of size ranging from 0.1 to 1mm throughout the cement-water matrix.

→ This action is when properly controlled causes a slight expansion in plastic concrete (or) mortar and thus reduces (or) eliminates voids caused by normal settlement that occur during the placement of concrete.

→ Water films around the minute bubble which prevents the concrete from bleeding.

→ Larger amount of water increase the expansion appreciably resulting in a gas filled light weight low strength concrete.

→ These are also called foamed concrete (or) aerated concrete (or) cellular concrete.

→ These concrete are light weight and used for thermal insulation.

4) Corrosion Inhibiting Admixture:-

→ Corrosion inhibiting admixtures are used to slow down corrosion of steel reinforcement in concrete.

→ They are used as a defensive strategy for concrete structures constructed in marine facilities, highway bridges / industrial environment where reinforced cement concrete is exposed to high concentration of chloride.

→ Compounds such as sodium benzoate, sodium nitrate etc can be used as corrosion inhibiting admixture.

→ A 2 percent benzoate solution is mixing with water may be used to prevent corrosion of reinforcement, sodium nitrate has been found to be effective in preventing corrosion of steel in concrete containing calcium chloride.

(5) Shrinkage reducing Admixture:-

- The shrinkage reducing admixture, also called expansion-producing admixture, either expand themselves or react with other constituents of concrete resulting in expansion.

→ This expansion may be of about the same magnitude as the drying shrinkage at later ages or may be little greater.

→ This concept has been used in the development of non-shrinking cement wherein the expansion producing compound is mixed with cement in appropriate proportion to get the desired expansion of shrinkage compensation.

- Higher proportion of expansion-producing admixture is employed to produce self stressing cements.
- shrinkage compensating type expansive cement is capable of developing 0.03 to 0.10 percent restrained concrete expansion.
- The high expansion self-stressing cement is generally capable of developing up to 0.25 percent restrained concrete expansion and can attain stress levels upto 7 MPa.
- This will be adequate to produce prestressed (precast) concrete members.
- Expansive cements have greater water demand than OPC. Larger water content gives enhanced workability to fresh concrete, better pumpability and easier finishing characteristics. However, to compensate for serious slump loss in hot weather a small dosage (0.05 percent) of citric acid can be used as a retarder.
- A number of expansion producing agents have been reported, such as granulated iron and chemicals, and anhydrous sulfoaluminate, etc. Granulated iron and chemicals promote oxidation of iron resulting in the formation of iron oxides, which occupies an increased solid volume.

These admixtures are employed in laying heavy machine foundations, patching, production of shrinkage-compensating concrete which is free from shrinkage cracks, and production of self-stressing and pre-stressed concretes, grouting the ducts of post-tensioned members, grouting foundation bolts, cast-in-situ joints of precast construction, and for introducing self-stress in the concrete. Shrinkage compensating expansive cements are particularly useful in avoiding cracking in large surface area concrete structures such as runways, continuous bridge decks, large parking area, large slabs etc.

(6) Water (or) Damp proofing Admixtures:-

→ Water under pressure and in contact with one surface of concrete, can be forced through channels between the two surfaces. The water passing in this manner is a measure of the permeability of concrete.

→ Water can also pass through concrete by the action of capillary forces. The materials used to reduce the water flow by the first method are termed permeability reducers, whereas the materials used to reduce second type of flow are more properly called damp-proofers.

→ A concrete having proper mix proportions, low water-cement ratio and sound aggregate will be impervious and need no additives. However, the resistance of concrete to the penetration of moisture can be improved by adding chemically active water repelling agents like soda and potash soaps to which are sometimes added lime or calcium chloride.

→ These admixtures prevent the water penetration of dry concrete, or stop the passage of water through unsaturated concrete. The water proofing admixture may be grouped into the following four categories.

1. Chemicals which react with hydration product of cement :-

→ These admixtures react with hydration products of cement and form thin hydrophobic layer within pores and voids and on surface of the concrete.

→ This type of admixture is based on liquid fatty acids present in vegetable and animal fats.

→ They may be in the emulsified form or pre-mixed with inert fillers such as talc or silica flour for uniform dispersion in the concrete mix.

2. Chemical which coalesce on contact with hydration product :-

→ These finely divided wax emulsions which break down on coming in contact with alkaline environment in cement concrete and form hydrophobic layers in pores, voids and on the surfaces.

3. Finely divided hydrophobic materials :-

Calcium- stearate and aluminium stearate form hydrophobic layers in the concrete pores and widely used in precast industry.

4. Finely divided fillers :-

Mineral additives such as pozzolanas, silica fume, kaolinite when added in lean concrete mix improves water tightness by pozzolanic action and with physical filler effect.

7. Bonding admixture :-

→ When fresh concrete is placed over a concrete surface already set and at least partially cured, the fresh concrete shrinks while setting which makes the new concrete pull away from the old surface.

→ Due to this reason, the old surfaces are usually prepared so that the aggregates are exposed and clean which makes the cement past in the freshly placed concrete, bond the aggregate in the same way as it bonds the aggregate in the new mix.

→ Cement paste slurry is often applied to the prepared old surface immediately prior to pouring new concrete to increase the amount of paste available at the surface for bonding purpose.

→ In situation where such a treatment cannot be applied the bonding admixtures can be used to join two surfaces.

→ These admixtures increase the bond strength between the old and new concrete.

→ The major application include overlay on an existing pavement, provision of screed over roof for waterproofing repair work, etc.

→ There are two types of bonding admixtures in common use. In the first type, the bonding is accomplished by a metallic aggregate and in the other type latex emulsions are used.

→ The metallic aggregate type of admixture type of admixture consists of fine cast iron particles to which is added a chemical that causes them to oxide rapidly when mixed with portland cement and water.

→ The rapid oxidation of the iron particles in the cement slurry applied over the old concrete surface results in the expansion of iron particles.

→ They tiny fingers that thrust out into both the old and the new concrete bind them together.

→ This admixture can also be used as waterproofing by applying additional coats. Successive coats build up a thin but dense watertight film over the surface.

→ There are a number of types of synthetic latex bonding admixtures, which essentially consist of highly polymerized synthetic liquid resins dispersed in water. The commonly used polymer bonding admixtures are made from natural rubber, synthetic rubber or any of a large number of organic polymers or copolymers.

→ The polymers include polyvinyl chloride, polyvinyl acetate, acrylics and butadiene styrene copolymers.

→ These admixtures are water emulsions which are generally added to the mixture in proportions ...nt to 5 to 20 percent by mass of cement depen...

8. Concrete surface - hardening Admixture :-

→ The plain concrete surfaces subjected to heavy traffic on the industrial buildings continuously subjected to wear and tear deteriorate after a period of time.

→ The factory floor, on account of movement of materials, iron tyred trollies, vibrations caused by running machines is likely to suffer damage. Wear resistant and chemical resistant floor must be provided in the beginning itself. Replacing and repairing of old floors will interfere with the productivity and prove to be costly.

→ The hardener commonly used to prevent the destruction of the surface can be divided into two groups, namely, the chemical hardeners and fine metallic aggregates.

→ The hardener commonly used to prevent the destruction of the surface can be divided into two groups, namely, the chemical hardeners and fine metallic aggregates. The liquid chemical hardeners consist of silicofluorides or fluosilicate and a wetting agent.

→ The latter reduces the surface tension of liquid and allows it to penetrate the pores of the concrete more easily. The chemicals combine with free lime and calcium carbonate present in concrete to bind the fine particles into highly wear resistant flint like topping.

→ On the other hand, the metallic hardeners consisting of specially processed graded iron particles are dry mixed with Portland cement which is spread evenly over the freshly floated concrete surface and are worked into concrete by floating. This gives highly wear resistant and less brittle concrete topping.

Sometimes abrasive materials like fine particles of flint, aluminium oxide, silicon carbide, or emery are used in the topping applied as dry shake to obtain water-resistant non-skid surfaces.

9. Concrete Coloring Admixtures or Pigments.

→ Pigments are the admixtures added to produce colored cements. One of the methods of producing colored concrete surfaces in modern construction is to use concrete paint to be applied after the concrete surface has been neutralized either through exposure or by using a neutralizing agent like zinc sulfate.

→ The other most commonly used method involves integrating color into the surface of concrete while it is still fresh. This can be accomplished by mixing natural metallic oxides of cobalt, chromium and manganese called pigments into the topping mix. This is the best way of distributing the colour evenly throughout the concrete.

→ The coloring admixture made with synthetic oxides mixed with one or more additional drying ingredients are also suitable. But the pigments used must be permanent and should not react with free lime in concrete. To obtain a good coloring effect, the pigments should be ground with the cement in a ball mill. Sometimes they are mixed with fillers, like chalk, but the excessive use of fillers may affect strength of concrete. The chief pigments used in concrete are as follows.

1 Black :- The best permanent black pigment is carbon black, but manganese black gives a brown tint and normal magnetic ferrous oxide has a purple-ish tint.

2- Blue :- The materials used are barium manganate and ultramarine. Sulphur fumes in polluted atmosphere adversely affect the former. Ultramarine is suitable for concrete used in non-wearing surfaces.

3- Brown :- Raw umber or burnt umber form satisfactory brown pigments.

4- Green :- Artificially producing chromium oxide and chromium hydroxide are suitable.

5- Red :- The most commonly used material is the naturally occurring red oxide of iron.

6- Yellow :- Hydroxides of iron give yellow colour.

10- Fungicidal, Germicidal and Insecticidal Admix-

-> Certain materials like polyhalogenated phenols, dieldrin emulsions and copper compounds when added as admixtures impart fungicidal, germicidal or insecticidal properties to the hardened cement pastes, mortars or concretes.

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* Workability :-

- The diverse requirement of mixability, stability, transportability, placeability, mobility, compactability & finishability of fresh concrete mentioned above are composite property.

→ Workability is that property of freshly mixed concrete (or) mortar which determines the ease & homogeneity with which it can be placed, compacted & finished.

→ Workability of a fresh mix concrete is a complex system of two critical parameters consistency & homogeneity.

→ A mixture could have a fluid consistency of fresh concrete varies from situation to situation. If it segregates it would not be very placeable, it be considered to have good consistency & homogeneity.

→ Thus for optimal purpose (or) performance the consistency & homogeneity must be balanced.

→ A concrete may not be workable when compacted by hand but may be satisfactory when vibration is used.

Consistency :-

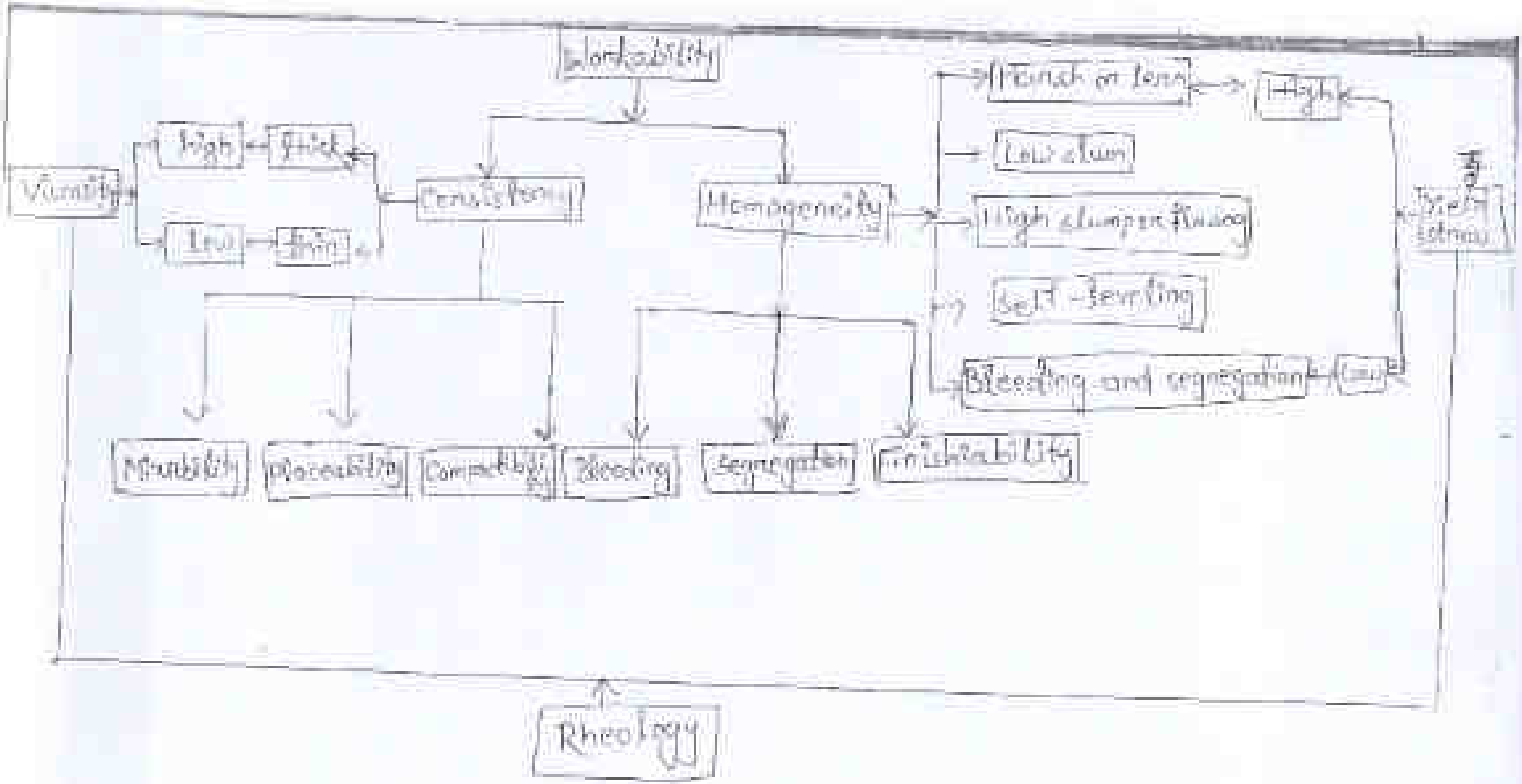
→ Consistency is relative mobility or ability of a freshly mixed concrete to flow and the usual measurements are slump for concrete, flow for mortar or grout and penetration resistance for neat cement paste.

→ It is thus a measurement of one dimension of workability. It does not indicate whether or not a low viscosity mix has the cohesion to be placed without segregation and bleeding.

-> Different concrete mixed with the same consistency can have different workability characteristics. Major factors affecting consistency are: water content; cement content and its characteristics; plasticity of the cement paste; aggregate content and its characteristics; air content; temperature; mixing conditions; chemical admixture and mineral additives used.

-> Addition of superplasticizer improves consistency by dispersing the cement particles and reducing the viscosity of the cement paste.

-> Increasing the water content will also improve consistency and can be resorted to if the negative effects of extra water represented by bleeding, segregation and lower strength can be tolerated.



Workability
Viscosity
High
Thick
Consistency
Low
Thin
Homogeneity
Mixability
Placeability
Compactability
Bleeding
Segregation
Finishability
Finish or loss
Low slum
High slump flow
Self-levelling
Bleeding and segregation
High
Low
Yield stress
Rheology

Homogeneity.

- which means uniform and stable distribution of cement, aggregate and water, and resistance to segregation is a critical physical property of plastic concrete.
- This property does not have standardized test method for its measurement. The standardized tests for measurement of workability, namely flow spread, and slump tests, measure consistency, not the homogeneity, to measure the homogeneity properties it is necessary to use a rheometer, an instrument that measures yield stress and plastic viscosity
- A reduction in viscosity increase flow and improve consistency. Low viscosity mortar with superplasticizer has relatively high stress and high plastic viscosity and therefore is more resistant to segregation and bleeding.
- Low viscosity is essential for ease of placement with cohesion. It should be noted that viscosity and plastic viscosity are different properties.
- The presence of excess mixing water, under mixing and overmixing are common cause of many problems related to physical properties of concrete in plastic and hardened state.
- The addition of superplasticizer improves the wetting out and mixability of the concrete mix. It reduces yield stress which means less mixing energy and time are required. It improves homogeneity of the various mineral additives and admixtures.

* Measurement of workability :-

→ The quantitative assessment describing concrete as being of high or low workability or semi-dry or plastic, etc. may mean different things to different people.

→ The commonly-used practice of defining this physical property by a numerical scale based on the empirical tests for its measurement has been found to be unsatisfactory in many subjective assessment rather than on empirical tests.

→ A number of different empirical tests are available for measuring the workability of fresh concrete but none of them is wholly satisfactory. Each test measures only a particular aspect of it and there is really no unique method which measures the workability of concrete in its totality.

→ However, by checking and controlling the uniformity of the workability, it is easier to ensure a uniform quality of concrete and hence uniform strength for a particular job. The empirical tests widely used are.

1. Slump test
2. Compacting factor test
3. Vee-Bee consistency test.
4. Flow test

→ A typical test apparatus of these four tests, the slump test is perhaps the most widely used, primarily because of the simplicity of the apparatus required and the test procedure.

→ The slump test indicates the behaviour of a compacted concrete cone under the action of gravitational forces.

→ The test is carried out with a mold called the slump cone. The slump cone is placed on a horizontal and non-absorbent surface and filled in three equal layers of fresh concrete, each layer being tamped 25 times with a standard tamping rod.

→ The top layer is struck off level and the mold is lifted vertically without disturbing the concrete cone. The subsidence of concrete in millimeters is termed the slump. The concrete after the test when slumps evenly all around is called true slump.

→ In the case of very lean concrete, one-half of the cone may slide down the other which is called a shear slump. or it may collapse in case of very wet concrete.

→ The slump test is essentially a measure of consistency or the wetness of the mix. The test is suitable only for concretes of medium to high workabilities (i.e. having slump values 25 mm to 125 mm) for very stiff mixes having zero slump, the slump test does not indicate any difference in concretes of different workability.

→ It must be appreciated that the different concretes of the same slump may, indeed have different workabilities under the site conditions.

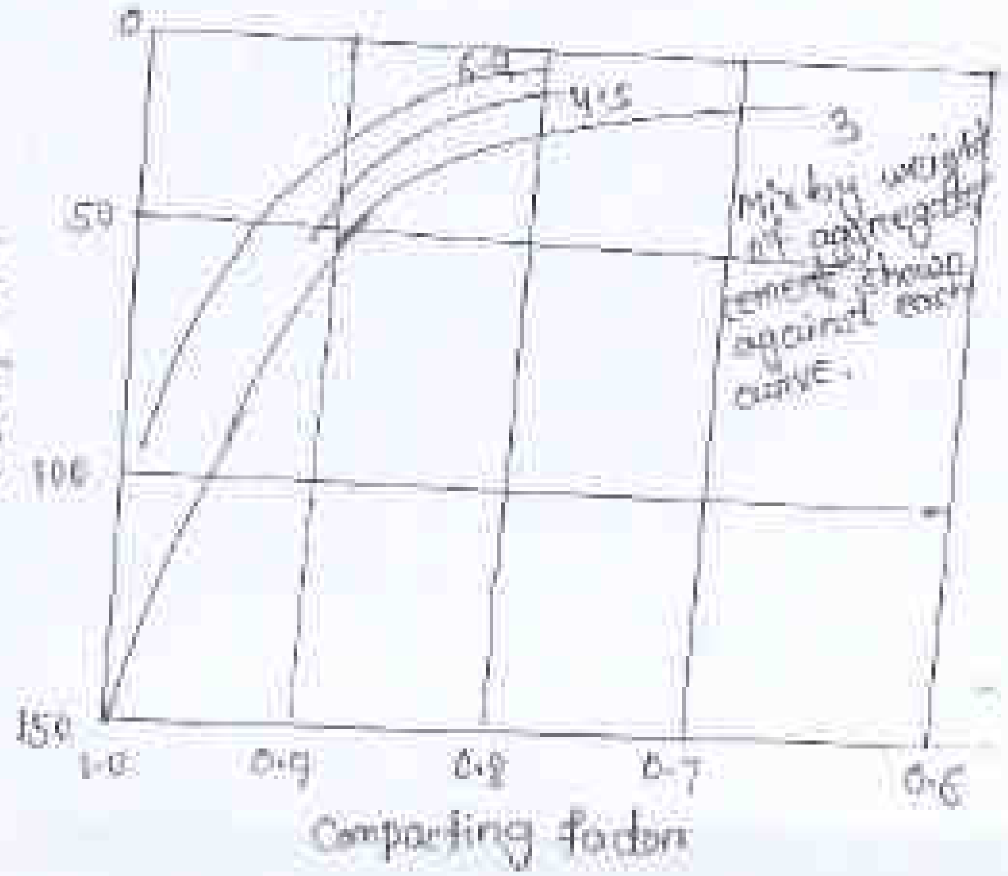
→ However, the slump test has been found to be useful in ensuring the uniformity among different batches of supposedly similar concrete under field conditions.

→ The slump test is limited to concretes with maximum size of aggregate less than 38 mm.

→ The compacting factor test gives the behavior of fresh concrete under the action of external force.

→ It measures the compactability of concrete which is an important aspect of workability, by measuring the amount of compaction achieved for a given amount of work.

→ The compacting for concrete mixes of medium and low workabilities i.e compacting factor of 0.9 to 0.8 ; because the test is more sensitive and gives , for concrete of very low workabilities of order of 0.70 or below, the test is not suitable , because this concrete cannot be fully compacted for comparison in the manner described in the test.



→ The vee-bee test is suitable for stiff concrete mixes having low and very low workability.

→ Compared to the slump test and compacting factor test, the vee-bee test has an advantages that the concrete in the test receives a similar treatment as it would in actual practice.

→ The test consists in molding a fresh concrete cone in a cylindrical container mounted on a vibrating table.

→ The concrete cone when subjected to vibration by starting the vibrator starts to occupy the cyllindrical container by the way of getting re-molded.

→ The remolding is considered complete when the concrete surface become horizontal.

→ The time required for complete remolding in second is considered as a measure of workability and is expressed as the number of vee-bee seconds.

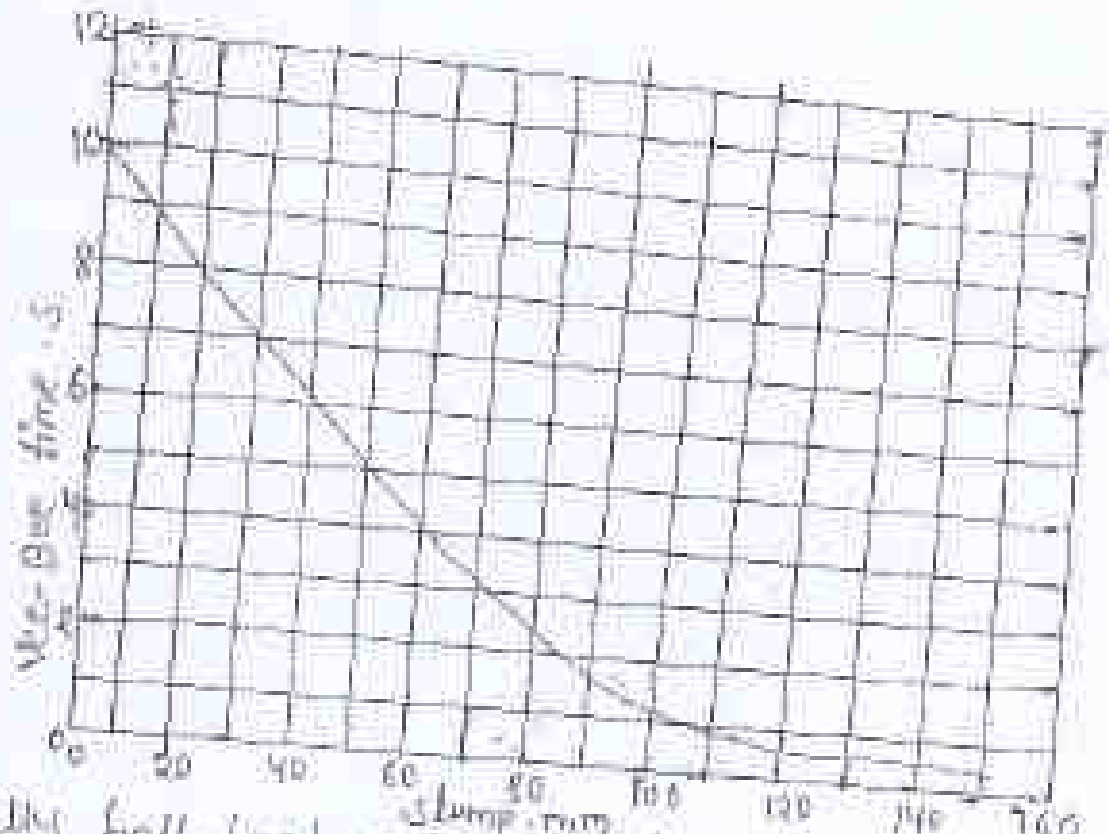
→ Since the end point of the test when the concrete surface becomes horizontal - is to be assertained visually, it introduces a source of error which is more pronounced for concrete mixes of high workability and consequently records low vee-bee time for concrete of slump in excess of 125mm the remolding is so quick that time cannot be measured.

→ The test is therefore, not suitable for concrete of higher workability that is slump 125mm or above.

→ Flow test gives the satisfactory performance for concretes of fine consistencies for which slump

can be used.
The test consists of moulding a fresh concrete cone on the top of the platform of flow table, and in giving 15 jolts of 12.5mm magnitudes.

→ The spread of the concrete, measured as the increase in diameter of cone.
→ Is taken as a measure of the flow on consistency of the concrete.
→ The test suffers from the draw back that the concrete may scatter on the flow table with a tendency towards segregation.



→ Kelly ball test, or BTM method, is a simple field method for measuring the consistency of plastic concrete.
→ The apparatus is a simple portable metal ball that penetrates the surface of concrete.
→ It can be performed on the in-place concrete

much faster and accurately.

- Test results are accurate, reliable and compare favourably with results obtained through the more commonly known and used slump test.
- The kelly ball test device consists of a cylindrical metal plunger with a hemispherically shaped metal ball of 150 mm diameter and 115 mm height at the bottom and a handle at the top.
- The total assembly weight is 13.6 kg.
- A stirrup frame guides the plunger and acts as reference for measuring the depth of penetration.
- The plunger is graduated for notice the penetration.
- The semicircular bearing plates at each foot of the frame serve to prevent the frame from lifting.
- There is movable pinch clamp which makes it easier to measure the depth of penetration.
- This clamp is attached to the top of the plunger where it remains until the ball has penetrated the concrete.
- Then the clamp is lowered until it comes in contact with the frame.
- When the entire apparatus is removed from the concrete the position of the clamp on the handle gives the depth penetration of ball.
- The apparatus can be mounted on a simple wooden base with a tin can for holding rags for wiping the ball clean test.

In addition to carrying the apparatus, it acts as a foot board for the person testing the wet concrete. The test can be performed quickly and easily at the job site either directly in the fresh concrete or in a separate container.

(1) The ball is held vertically by the handle and brought in light contact with the concrete surface. The zero mark on the rod should appear at the level of the frame.

(2) The handle is released and the ball is allowed to sink freely into the concrete. The depth of the penetration is indicated by the reading on the plunger which has slipped up through the frame from the zero mark. It is not necessary to make any adjustment for the slight sinking of the bearing plates into the concrete.

(3) At least three separate measurements of penetration are carried out for each batch. Each test is performed with the foot of the frame at least 150mm away from the placed where it rested in the previous test. The consistency is based on an average of first three pene-tration readings. A penetration of 25mm;

measured by the kelly ball method approximately corr-
pondis about 25mm of slump.

→ The following precautions should be taken.

(a) If the test is performed at the size the press
-on should be measured at least 225 mm away
from the nearest face of any forms on wall. In case
of pavement concrete test, the horizontal distance
of 225mm is between the penetration point on the
subgrade and the form edge of the finished lower
section of concrete.

(b) The minimum depth of concrete to be tested consist
-ency should be more than the largest of 150 mm
on three times the maximum size of the aggregate
used.

(c) The surface to concrete to be tested for consiste
-cy should be smooth and level. The disturbance of the
concrete caused by the ball should be limited to
as small an area as possible.

→ The major advantage of the kelly test is that
it can be performed at the job site thus eliminati
-ng the time and efforts required to prepare samp
-les to be sent to the laboratory.

→ Three or more kelly ball tests can be made in
a time less than it takes to make one slump test,
thus eliminating any delay in finishing operations.

→ The kelly ball test device is easy to carry to the
job site and can be used for further test simply
by cleaning the ball with an oily rag.

→ The kelly ball device can be used for measuring
the consistency of stiff mixture of concrete with

→ The [illegible] for measuring the [illegible] only as a [illegible] [illegible] for the [illegible] [illegible] and concrete.
Large size coarse aggregate as long as adequate depth is available for penetration.

→ Lightweight concrete and mass concrete containing aggregate as large as 150mm can be tested in the areas free from these large stones.

→ As each of the above tests measures only a particle aspect of workability there is no right correlation between the workability of concrete as measured by different test methods.

→ In the absence of definite correlations between different measures of workability under different conditions i-at has been recommended that, for a given concrete, the appropriate test method be decided be fore hand and workability be expressed in terms of such a test only rather than than be interpreted from the results of other-test.

→ In addition to the specific faults inherent to each test, the major drawbacks are summarized below

(1) The tests are quite arbitary and empirical as far as the measurement of workability is concerned because each of these test is a single point test measuring a single quantity which at times may classify two such concrete identical which may behave quite different by on the job.

(2) The results from these tests are influenced by minor variations in technique of carrying out the test.

Properties of fresh concrete :-

① strength :-

→ Concrete has good strength against compression & it is moderately weak in tension & bending.

→ Compressive strength of concrete is mainly defined by the amount of cement applied, but it also influenced by the ratio of water to cement, improper mixing & placing as well as the suitability & range of hydration & curing.

→ Tensile strength generally varies from 7 to 8% of compressive strength and raised with the addition of steel & fibre reinforcements.

② Durability :-

→ Durability means the capacity to retain standing performance over an expanded service life.

→ Concrete uncovered on the outside of a building should have good resistance capacity against weathering freezing & thawing in order that it doesn't lose it's strength from relation

③ Volume stability :-

→ All materials are enlarged & contracted with variations in temperature & as the concrete is a porous material, it also enlarged & contracted with variations in moisture content.

→ Cement based product like concrete, concrete masonry these are undergoes shrinkage by evaporation of moisture.

→ Extreme shrinkage can lead to crack as a result the moisture enters into concrete

④ Workability :

→ Workability belongs to the relative ease with which a fresh concrete mix is treated, arranged, compacted & finished devoid of segregation (or) separation of the materials.

→ Proper workability is necessary to form inexpensive & superior quality concrete.

→ Fresh concrete contains strong workability if it can be developed, compacted & finished to it's final shape

(5) Consistency :-

→ Consistency stands for the aspect of workability associated with the flow characteristics of fresh concrete.

→ It signifies the fluidity of wetness of a mix & it's computed with slump test.

→ A high-slump concrete mix is very fluid where as a lower slump concrete is drier & more hard.

⑥ Cohesiveness :-

→ Cohesiveness means the element of workability which specifies whether a mix is harsh, sticky or plastic.

→ Harshness may occur by an excess of rough, angular flat (or) elongated aggregate particles.

Requirements of workability :-

- The workability of fresh concrete should be such that it can be placed in the form work and compacted with minimum effort, without causing segregation and bleeding
- The choice of workability depends upon the type of compacting equipment available, the size of the section and concentration of reinforcement.
- compaction by han using rodding and tamping is not possible when compacting factor is less than 0.85
- Ordinary techniques of vibration are not applicable if the compacting factor falls below 0.70
- In such cases, techniques like vibro-pressing have to be adopted when
- heavily reinforced sections or when the sections are narrow or contain inaccessible parts or when the spacing of reinforcement makes the placing and compaction difficult, the workability should be high to achieve full compaction with a reasonable amount of effort
- The requirements of workability generally required for different conditions of placement of concrete
- The range of values indicates are considered suitable for concretes having aggregate of a nominal maximum size of 20mm
- The value of workability will generally increase

with the increase in the size aggregate and will be somewhat lower for aggregate of smaller size than indicates

→ The workability should be assessed depending upon the situation at hand.

→ The aim should have the minimum possible workability consistent with satisfactory placement and compaction of concrete.

→ An insufficient workability may result in incomplete compaction, ~~[illegible]~~ there by severely affecting the strength, durability and surface finish of concrete and may indeed prove to be uneconomical in to long run.

segregation and Bleeding:-

→ The stability of a concrete mix requires that is should not segregate and bleed during transportation and placing.

→ Segregation can be defined as separating out of the ingredients of concrete mix so that the mix is no longer in a homogeneous condition.

→ Only a stable homogeneous mix can be fully compacted.

→ Two types of segregation can occur

(1) The separating of coarser particles in a dry mix, termed segregation.

(2) Segregation of cement paste from the mix in the case of lean and wet mixes termed bleeding.

→ The segregation depends upon handling and placing operations.

→ The tendency to segregate increases with the maximum size of the aggregate, amount of coarse aggregate and with the increased slump.

→ The tendency to segregate can be minimized by

(1) Reducing the height of drop of concrete

(2) Not using vibration as a means of spreading a heap of concrete into a level mass over a large area and.

(3) Reducing the continued vibration over a longer time, as the coarse aggregate tends to settle to the bottom and the scum rises to the surface (this formation of scum is termed laitance)

→ The segregation of coarse particles in a lean dry mix may be corrected by the addition of a small quantity of water which improves cohesion of the mix.

→ Bleeding is due to rise of water in the mix to the surface because of the inability of the solid particles in the mix to hold all the mixing water during the setting of the particles under the effect to compacting.

→ Bleeding causes the formation of a porous weak and non-durable concrete layer at the top of place of concrete.

→ In case of lean mixes bleeding may create capillary channels to increasing the permeability of concrete.

→ When concrete is placed in different layers, and each layer is compacted after allowing certain time to lapse before the next layer is laid, bleeding may also result in a plane of weakness b/w layers.

→ Any laitance formed should be removed by brushing and washing before a new layer is added.

→ Over compacting the surface should be avoided.

Factors Affecting workability:-

→ The workability of fresh concrete depends primarily on the properties of constitutional materials, mix proportions and environmental conditions.

→ Workable concrete exhibits very little internal friction between particles and over comes the frictional resistance offered by the formwork surface on reinforcement contained in the concrete with an appropriate amount of compacting effects.

Influence of mix Proportions:-

→ In the concrete comprising a cement aggregate & water system, the aggregate occupy approximately 70 to 75% of the total volume of economy demands that the volume of aggregates should be a large as possible.

→ The total specific area of aggregate is to be minimized to the extent possible by proper choice of size, shape and proportions of fine and coarse aggregate.

→ In a well-graded aggregate, different size fractions are so chosen as to minimize the void content and such a mixture will need more water for lubricating effects to overcome the reduction in mobility due to dense packing of particles.

→ However when the total voids are less, for the given amount of paste the mixture becomes cohesive and fatty which prevents segregation of particles and lubricated aggregate particles slope as well as fill the voids in the aggregate.

→ In a lean concrete, i.e., a concrete with high aggregate cement ratio, less quantity of cement paste per unit surface area of aggregate is available for providing lubrication and hence the mobility of aggregates be restrained. On the other hand, in case of rich concrete with low aggregate-cement ratio, more paste is available to make the mix cohesive and fatty to give better workability.

Influence of Aggregate Properties:—

The effect of aggregate proportions on the workability of fresh concrete can be summarized as follows:

1. For the same volume of aggregate in concrete, the use of coarse aggregate of larger size and/or rounded aggregate gives higher workability because of reduction in total specific surface area and inter-particle frictional resistance.

The lesser the surface area the lesser will be the amount of water required for wetting the surface and consequently lesser cement paste will be required for lubricating the surface of aggregates to reduce internal friction.

The influence of surface texture on workability is due to the fact that the total surface area of rough textured aggregate is more than the surface area of smooth rounded aggregate of same volume.

7 The use of angular, elongated or flaky aggregate results in low workability, primarily due to increase in the void content and inter-particle interference.

7 This explains the reasons why river sand and gravel provide greater workability

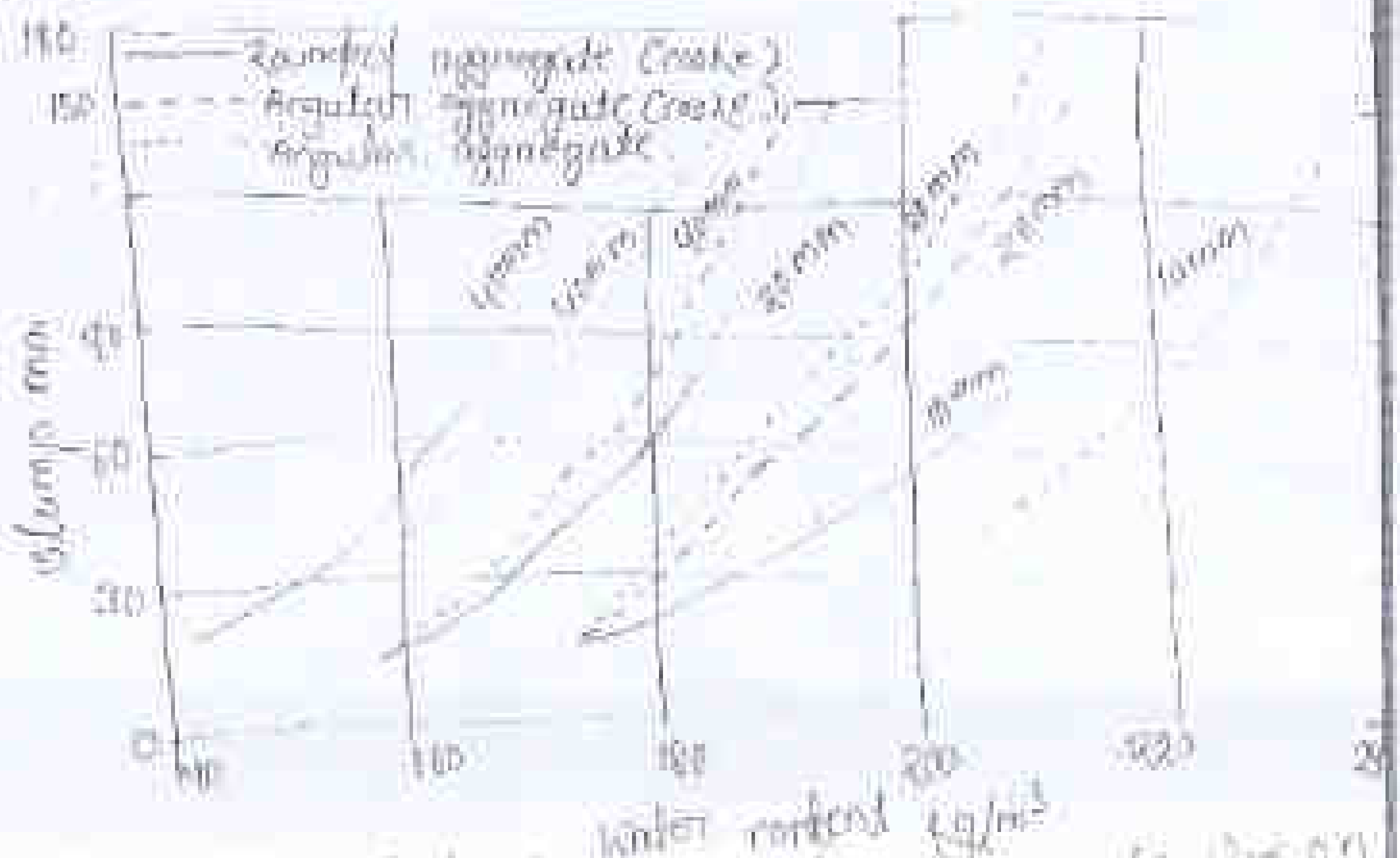
7 to concrete than crushed sand and aggregate. The size and shape of the aggregate is of paramount importance in the case of present day high strength and high performance concretes where very low water-cement ratios of the order of about 0.25 are used.

2. The use of finer sand increases the specific surface area, thereby increasing the water demand for the same workability. In other words for the same water content, the use of fine sand decreases workability.

Because of the greater contribution to the total specific surface area, the grading of fine aggregate is more critical than the grading of coarse aggregate

Nevertheless, the proportion to fine to coarse aggregates should be so chosen as neither to increase the total specific surface area (by excess of fine aggregate) nor to increase the particle interference (due to deficiency in fine aggregate). An unsuitable choice of overall grading can produce honeycombing or segregation. In normal range of mixes through an increase in fines content improves workability. In practice, there is an optimum fines content for maximum workability such that either an increase or decrease of fines reduces workability.

4. Generally, the mixes with higher water-cement ratio would require a somewhat finer grading and for mixes with low water cement ratio (as in case of high strength concrete) a coarser grading is preferable. The effect of water content and aggregate size



effect of water content and aggregate size on ...

the workability of concrete.

5. The workability is also effected by the physical and chemical properties of cement, but to a much lesser extent than that by the aggregate properties. The influence of cement properties may have to be taken into account especially for richer mixes. A rapid-hardening cement will have reduced workability as compared to ordinary Portland cement because of its higher specific surface and the fact that it hydrates more rapidly, and also the fineness of cement has an influence on bleeding.

Influence of Admixtures

→ The presence and nature of admixtures and mineral additives affect the workability considerably. As described in chapter 5, the plasticizers and super-plasticizers improve the workability manyfolds.

→ It is to be noted that initial slump of concrete mix, also called the slump of reference mix should be about 20-30 mm to enhance the slump manyfold at a minimum dosage.

→ Use of air-entraining agents which are normally surface-active, reduces the internal friction between the particles. The air bubbles may be considered as artificial fine aggregates of very smooth surface.

→ They also act as a kind of ball bearing between the particles to slide past each other and give easy mobility to the particles. Similarly, the fine glassy pozzolanic materials, in spite of increasing the surface area, offer better lubricating effects for giving better workability.

Effect of Environmental Conditions

→ The workability of a concrete mix is also affected by the temperature. On a hot day it becomes necessary to increase the water content of the concrete in order to maintain the desired workability. The amount of mixing water required to bring about a certain change in workability also increases of temperature.

Effect to Time

→ The fresh concrete loses workability with time, mainly because of the loss of moisture due to evaporation. A part of mixing water is absorbed by aggregate or lost by evaporation in the presence of sun and wind, and part of it is utilized in the chemical reaction of hydration of cement.

→ The loss of workability varies with the type of cement, the concrete mix proportions, the initial workability and the temperature of the concrete.

→ On an average a 125 mm slump concrete may lose about 50 mm slump in the first one hour.

→ The workability in terms of compacting factor decreases by about 0.1 during the period of an hour from the time of mixing.

→ The decrease in workability with time after mixing may be more pronounced in concrete with admixtures like plasticizers. For some particular total time after mixing, the loss in the strength of hardened concrete simply by adding extra water.

Workability	Compaction factor
Very low	0.78
Low	0.85
Medium	0.92
High	0.95

Work description	Workability measurement		Vee-Bee time (seconds)
	Slump (mm)	Compaction factor	
Moist earth	–	–	40 to 25
Very Dry	–	0.70	20 to 15-10
Dry	0-25	0.75	10 to 7-5
Plastic	25-50	0.85	5 to 4-3
Semi fluid	75-100	0.90	3 to 2-1
Fluid	150-175	0.95	More fluid than 1

1.06.07.2

Properties of hardened concrete

New Chapter

→ The principal properties of hardened concrete which are of practical importance are those concerning its strength, stress-strain curve characteristics, shrinkage & creep deformations, response to temperature variation, permeability & durability.

→ The strength of concrete at a given age under given curing conditions is assumed to depend mainly on water-cement ratio & degree of compaction.

→ Abrams water-cement law in this connection is well known.

→ Probable it is more correct to relate the strength of concrete to the concentration of the solid products of hydration of cement in the space available for these products.

→ The voids present in concrete mass have been found to influence greatly the strength of concrete.

* Strength of concrete:-

(i) Compressive strength:-

(ii) flexural strength

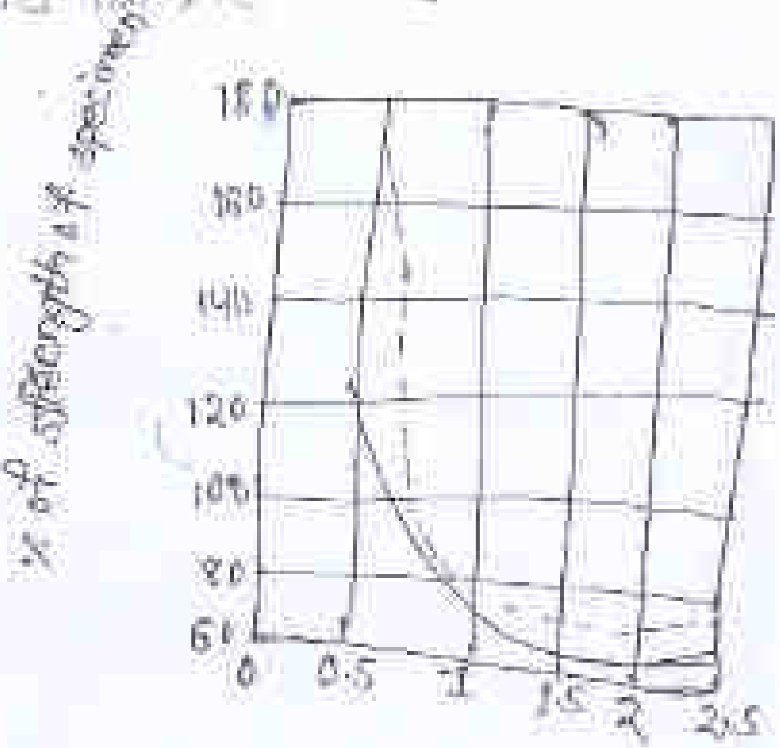
→ Of the various strength of concrete, the determination of compressive strength has more by cube (or) cylinder.

→ The cube are usually of 100mm (or) 150mm cube, the cylinder are 150 mm diameter by 300mm height.

→ The specimens are cast, cured & tested as per standards prescribed for each test.

→ While cylinders are used they have to be capped before the test.

→ The compressive strength given by different specimens for the same concrete mix are different.



H/D = Ratio of height of specimen to the lateral dimension

2) Flexural strength:-

→ The determination of flexural tensile strength is essential to estimate the load at which the concrete may crack.

→ As it is difficult to determine the tensile strength of concrete by conducting a direct tension test, it is computed by flexure testing.

→ The flexural tensile strength at failure or the modulus of rupture is thus determined & used when necessary.

→ It is useful for designing of pavement slabs & airfield runway as flexural strength or tension is critical in these cases

→ The modulus of rupture is determined by testing standard test specimens of 150mm x 150mm x 700mm over a span of 600mm (or) 100mm x 100mm x 500mm, over a span of 400mm, under symmetrical two-point loading.

→ The modulus of rupture is determined from the moment at failure as $f_r = \frac{M}{Z}$

→ Thus, the computation of f_r assumes a linear behaviour of the material up to failure which is only a rough estimation.

→ The results are affect by the size of specimen, casting curing and moisture conditions, manner of loading, rate of loading.

→ The test is conducted & the strength is determined according to the prescribed standards.

→ The strength estimated by flexure test is higher than the tensile strength of concrete because of the assumption of the linear behavior of material up to failure in the computation of f_r.

→ The accidental eccentricity in the direct tension test may also lower the apparent tensile strength.

→ In the direct tension test, as the entire volume of specimen is under maximum stress, the probability of weak element occuring in the body of specimen is High.

3) Tensile strength :-

→ Apart from flexural test, the other methods used to determine the tensile strength of concrete can broadly classified as direct and indirect methods.

→ The direct methods suffer from a number of difficulties related to holding the specimen properly in the testing machine without introducing stress concentration and to the application of uniaxial tensile load which is free from eccentricity to the specimen.

→ Even a very small eccentricity of load will induce bending and axial force conditions and the concrete fails at apparent tensile stess other than the tensile strength.

→ Because of the difficulties involved in conducting the direct tension test a number of ~~in~~ indirect methods have been developed to determine the tensile strength. In these tests, in general a compressive force is applied to a concrete specimen in such a way that the specimen fails due to tensile stress induced in the specimen.

→ The ~~tensile~~ stress at which failure occurs is the tensile strength of concrete.

→ The splitting test are well-known indirect tests used for determining the tensile strength of concrete, sometimes ~~test~~ referred as the splitting tensile strength of concrete.

→ The test consists of applying compressive line loads along the opposite generators of a concrete cylinder placed with its axis horizontal between the platens. Due to the applied line loading a fairly ~~uniform~~ tensile stress is induced over nearly two-third of the loaded diameter as obtained from an elastic analysis.

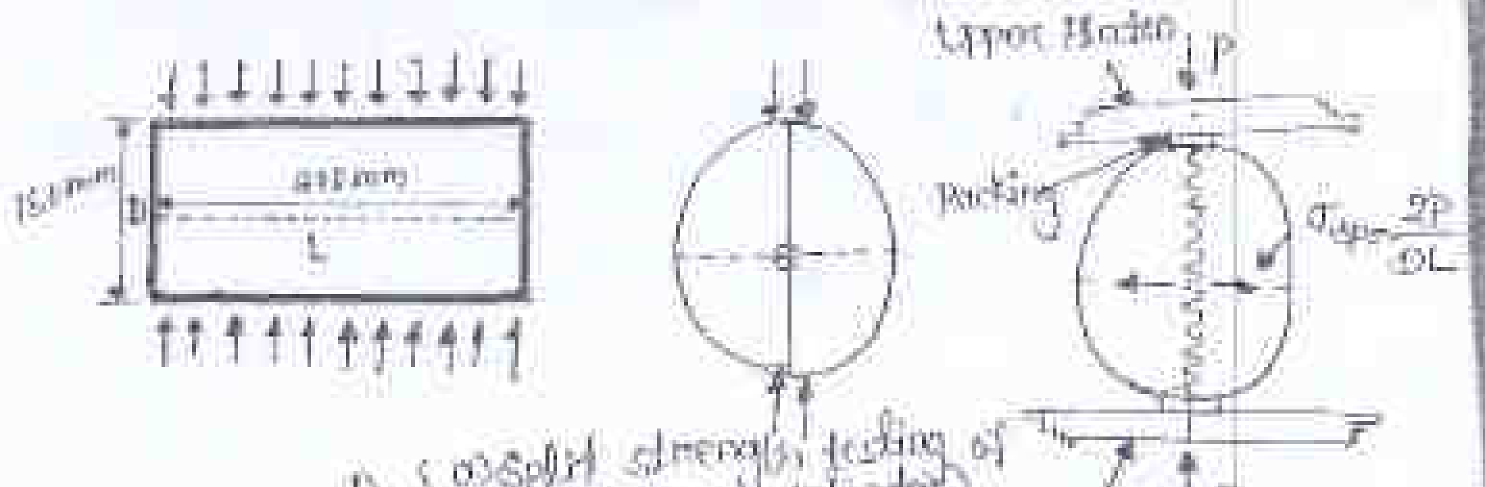
→ The magnitude of this tensile stress (acting in a direction perpendicular to the line of action of applied compression) is given by

$\frac{2P}{\pi DL} = 0.637P/DL$, where P is the applied load and D and L are the diameter and length of the cylinder respectively.

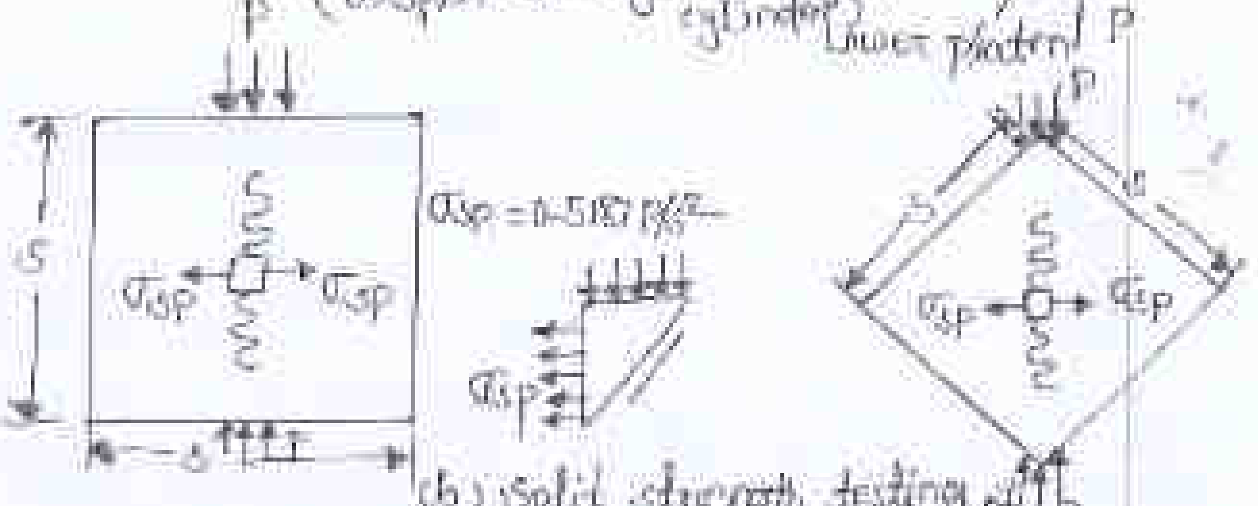
→ Due to this tensile stress, the specimen fails finally by splitting along the loaded diameter and knowing P at failure the tensile strength can be determined.

→ The test can also be performed on cube by splitting either (i) along its middle parallel to the edges by applying two opposite compressive forces through 15 mm square bars of sufficient length or (ii) along one of the diagonal planes by applying compressive forces along two opposite edge.

→ In the case of side-splitting of the cubes the tensile strength is determined from $0.642\,P/s^2$ and in diagonal splitting it is determined from $0.5187\,P/s^2$, where P is the load at failure and S is the [illegible]



(a) Split strength testing of cylinder



(b) Split strength testing of cubes.

> The relationships between compressive strength and split tensile strength and flexural strength and split tensile strength and flexural strength are given in respectively.

Advantages of the splitting test for determining the tensile strength are as follows.

1. The test is simple to perform and gives more uniform results than other tension tests.
2. The strength determined is closer to the actual tensile strength of the concrete than the given by the modulus of rupture test.
3. The same molds can be used for casting specimens for both compression and tension tests.

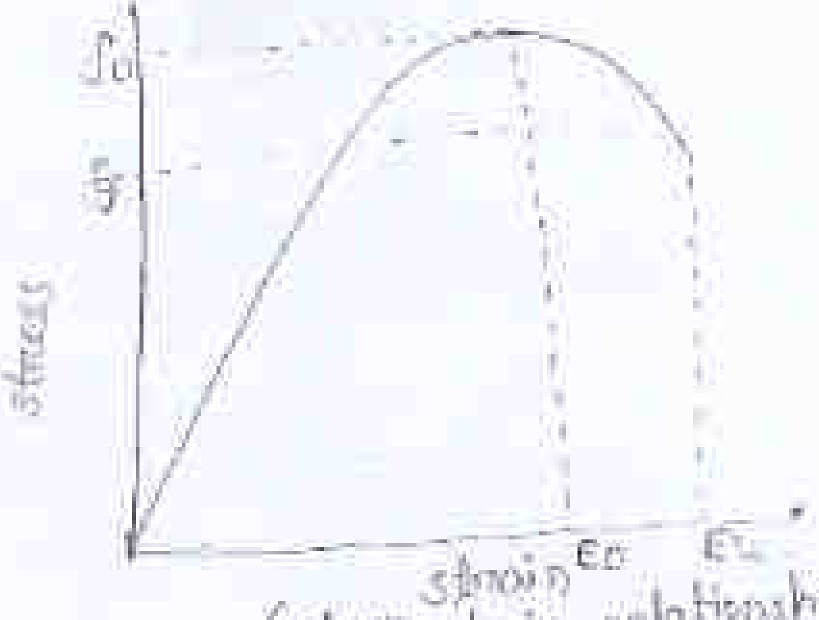
> The splitting tests have also been performed on prisms, i.e. on one-half of the specimen

left after performing the modulus of rupture test splitting-type tests have also been done on the ring specimens to determine tensile strength. Mortar and concrete rings have been tested by subjecting them to internal pressure.

→ The double punch test is another test performed on concrete cylinders to determine the tensile strength.

* stress - strain characteristics of concrete :

→ The relation is fairly linear in the initial stages but subsequently becomes non-linear reaching a maximum value and then a descending portion is obtained before.



(stress-strain relationship for concrete)

→ concrete finally fails. The curve is usually obtained by testing a cylinder with a height to lateral dimension ratio of at least 2, the test being conducted under uniform rate of strain. If a uniform rate of stress is adopted, it will not be possible to obtain the descending portion of stress and strain curve beyond the maximum stress.

→ The equation representing the stress and strain curve completely should satisfy the following conditions.

(i) at $f = 0$, $\varepsilon = 0$ and $\frac{df}{d\varepsilon} = E_c$

(ii) at $f = f_0$, $\varepsilon = \varepsilon_0$ and $\frac{df}{d\varepsilon} = 0$

(iii) at $f = f_1$, $\varepsilon = \varepsilon_u$

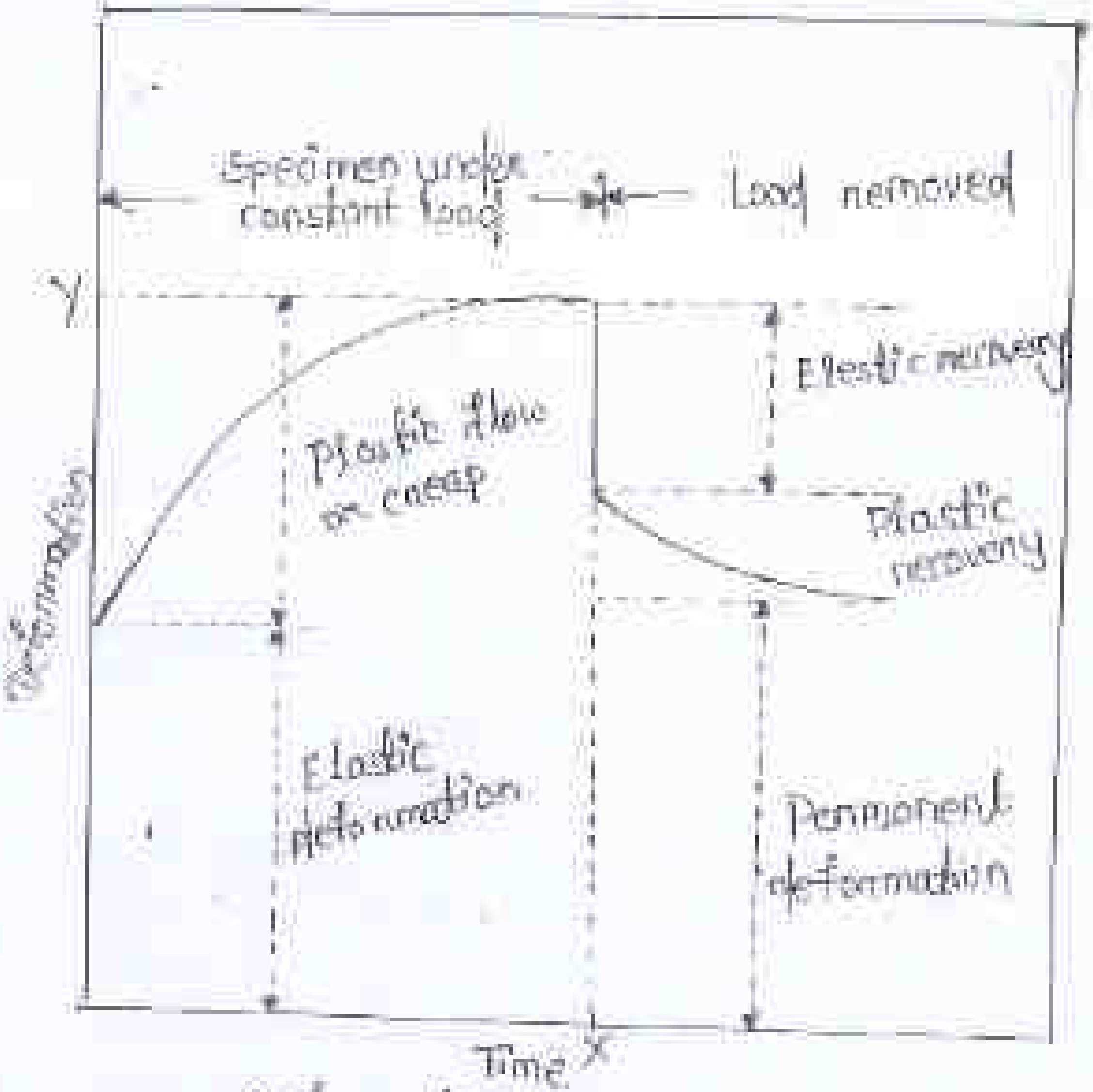
→ The equation satisfying all these conditions is used in the limit state design method. In another case, some simplifying assumptions are made.

→ One of the major assumptions is made in approximating the stress-strain curve to a straight line, i.e. treating the concrete as linearly elastic material.

→ This approximation is used in working stress method of design of structural concrete without much loss of accuracy up to about 50 percent of f_0.

→ Concrete is not strictly elastic in the sense that if it is unloaded after being stressed to $0.5 f_0$ or less a permanent set is noticed. However, the magnitude of the permanent set gradually decreases with more cycles of loading and unloading (within $0.5 f_0$) and the stress-strain curve tends to become a straight line.

→ The creep deformation of concrete also varies linearly with the sustained stress up to a value of $0.5 f_0$. Hence, for all practical purpose, the concrete could be considered as a linear elastic material when stress does not exceed $0.5 f_0$.



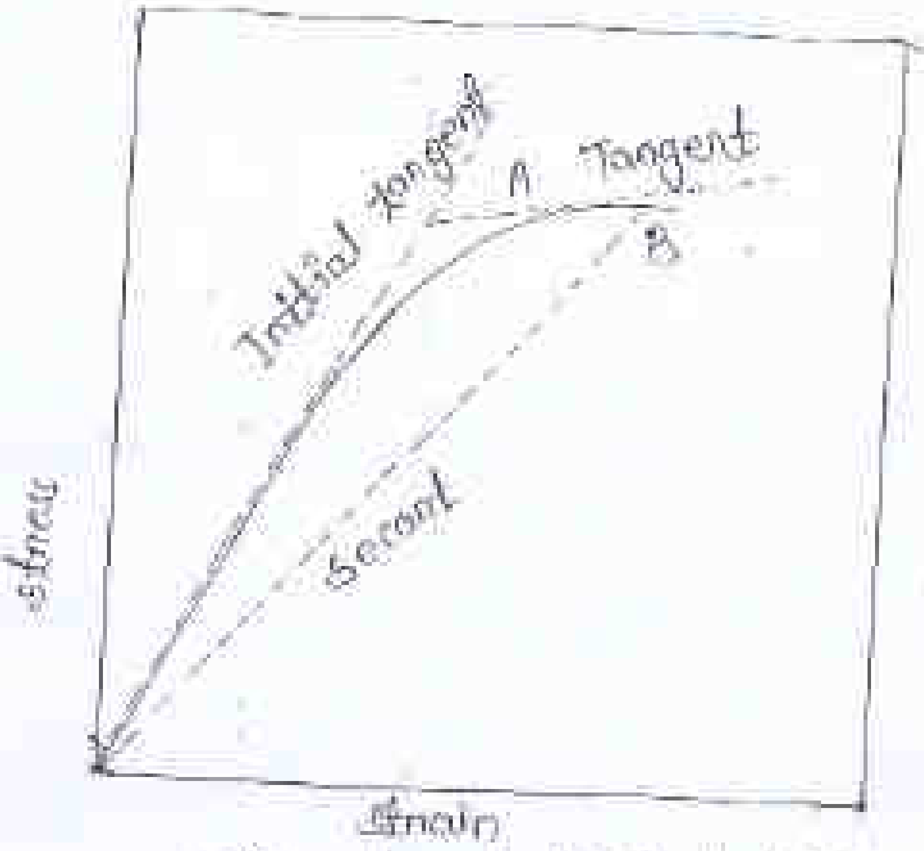
Deformation of hardened concrete under load

Modulus of Elasticity

-> The modulus of elasticity of concrete would be a property for the case when the material is treated as elastic.

-> If we consider the stress-strain curve of the first cycle, the modulus could be defined as initial tangent modulus, secant modulus, tangent modulus or chord modulus.

-> In the laboratory determination of the modulus of elasticity of concrete, a cylinder is loaded and unloaded (stress not exceeding one-third of f_c) for three or four cycles, the stress-strain curve is plotted after the residual strain has become almost negligible and the average slope of stress-strain curve is taken.



different moduli of elasticity

→ The above modulus of elasticity is sometimes termed the static (secant) modulus of elasticity in comparison with dynamic modulus of elasticity obtained by vibration tests of concrete prisms or cylinders.

→ The latter is approximately equal to the initial tangent modulus and hence greater than the static or secant modulus.

→ Non-destructive test (NDT) procedure using electronic test system can be used to determine the dynamic modulus of elasticity of the concrete.

→ In this method, pulses of compression waves are generated by an electro-acoustical transducer that is held in contact with one surface of the prismatic or cylindrical concrete specimen.

→ After traversing through the concrete, the pulses are received and converted into electrical energy by a second transducer located at a distance L from the transmitting transducer.

-> The pulse velocity $V = L/T$ is related to the physical properties of a solid by the equation

$$V^2 = (K)\frac{E_d}{\rho} \quad \text{or} \quad E_d = \frac{\rho V^2}{K}$$

where:

L: distance between transducers, m

T = transit time, seconds.

Ed: the dynamic modulus of elasticity, Pa (N/m^2)

V: pulse velocity, m/s

ρ: the mass density, kg/m^3

K = 1 (for a cylindrical specimen)

In an alternative procedure the concrete specimen is subjected to longitudinal vibration and the resonant frequency of the specimen is determined. The dynamic modulus of elasticity can be calculated from the relation.

$$E_d = K\rho n^2 L^2$$

If L and ρ measured in millimeters and ρ in kg/m^3 then.

$$E_d = (4\rho n^2 L^2) \times 10^{-15} \text{ GPa}$$

-> The test method does not apply to the propagation of other types of vibrations within the concrete.

-> The approximate relationship between the static and dynamic moduli of elasticity is expressed by

Dimensional stability . shrinkage and creep:-

-> Dimensional stability of a construction material refers to its dimensional change over a long period of time.

-> If the change is so small that it will not cause any structural problems, the material is dimensionally stable. For concrete, drying shrinkage and creep are two phenomena additional to the deformation due to loads which compromise its dimensional stability.

-> The creep is the deformation suffered by concrete when it's subjected to a sustained load, and shrinkage, a contraction suffered by concrete even in the absence of load.

-> The relative magnitudes of shrinkage, creep and elastic strains are of the similar order.

-> The term volume change is often used to refer to the change in volume that occurs due to the shrinkage, creep, temperature and possibly chemical disintegration.

-> Shrinkage and creep are often discussed together because they are both governed by the deformation of hydrated cement paste within concrete.

-> The aggregate in concrete does not shrink or creep, and they serve to restrain the deformation.

-> Two types of shrinkage strains are recognised namely, plastic and drying shrinkage.

Plastic shrinkage:-

-> The hydration of cement causes a reduction in the volume of the system of cement plus water to an extent of about one percent of the volume of dry cement.

for normal weight concrete $E_c = 1.25 E_d - 19$

For lightweight concrete: $E_c = 1.04 E_d - 4.1$

Poisson's Ratio

→ It is determined as the ratio of lateral to longitudinal strain in compression test and may vary from 0.15 to 0.21.

→ The poisson's ratio can also be determined from the fundamental resonant frequency of longitudinal vibration of concrete specimen using ultrasonic pulse velocity method. The poisson's ratio can be determined from

$$\left(\frac{V^2}{2nL}\right) = \frac{1-\mu}{(1-2\mu)(1+\mu)}$$

where

V = pulse velocity, mm/s

n = resonant frequency of longitudinal vibration in Hz

L = distance between transducers, mm.

The value of Poisson's ratio as determined by dynamic tests is slightly higher and ranges from 0.20 to 0.25.

Plastic shrinkage

→ The hydration of cement causes a reduction in the volume of the system of cement plus water to an extent of about one percent of the volume of dry cement. It is plastic strain and is aggravated.

→ This contraction is due to loss of water by evaporation from the surface of concrete, particularly under hot climate and high winds. This can result in surface cracking.

→ This contraction is plastic strain and is aggravated due to loss of water by evaporation from the surface of concrete, particularly under hot climate and highwinds. This can result in surface cracking.

Drying shrinkage:-

→ The shrinkage that takes place after the concrete has set and hardened is called drying shrinkage. It takes place in the first ... and most of it takes place in the first few months (it also coincides with the period of active creep and thus the two are intricately related).

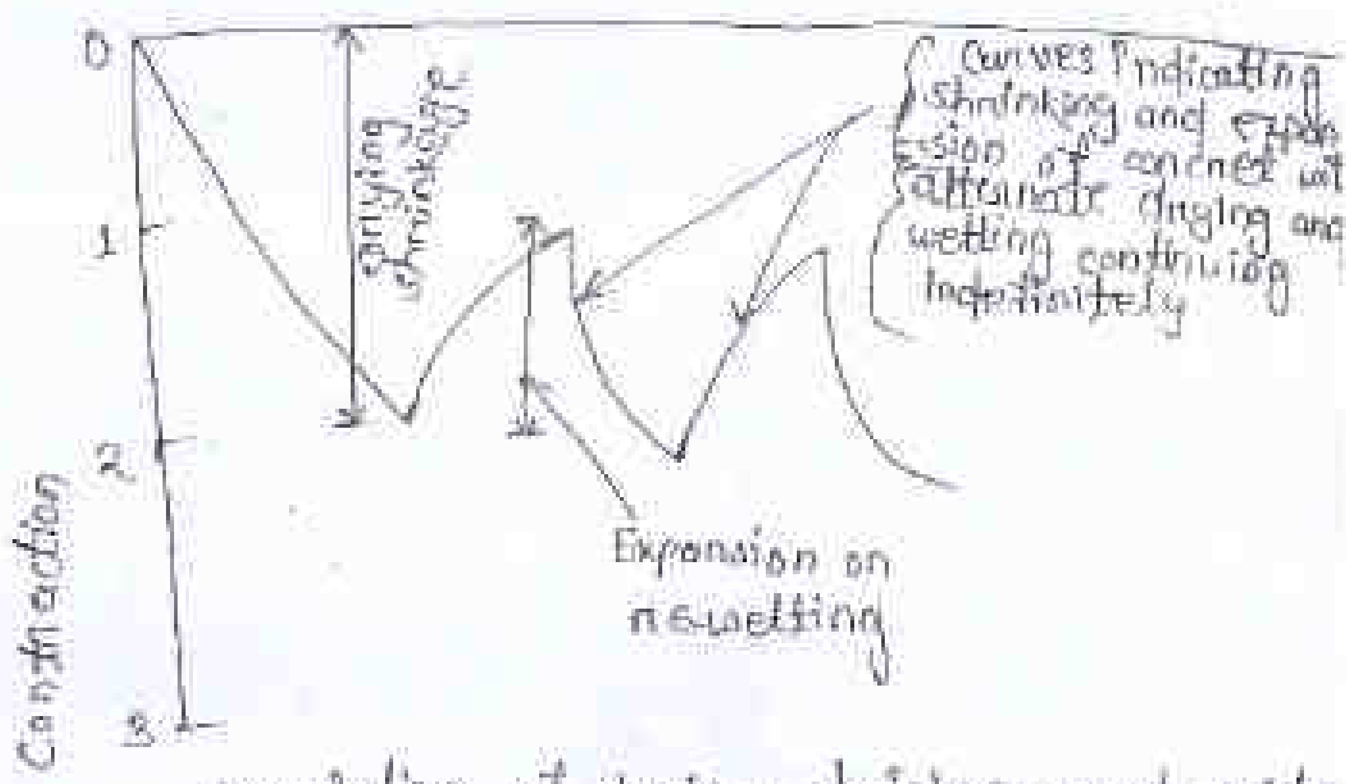
→ withdrawal of water from concrete stored in unsaturated air voids causes drying shrinkage.

→ A part of this shrinkage is recovered on immersion of concrete in water.

→ It is termed moisture movement. In the absence of other reliable data, the shrinkage can be estimated from Schorer's formula.

$$E_s = 0.00125 (0.90 - h)$$

where E_s is shrinkage strain and h represents relative humidity expressed as a fraction. In an environment of average humidity of 50 percent $h = 0.5$, $E_s = 0.0005$ and it may be noticed that in fully saturated condition ($h = 1.0$), $E_s = -0.000125$ which indicates swelling.



variation of drying shrinkage and moisture movement with alternate drying and wetting

The shrinkage is affected by:-

1. Water-cement ratio:- The shrinkage increases with the increase in the water-cement ratio.

2. cement content:-
The shrinkage increases with cement content but is inter-related to water-cement ratio because of the necessity to maintain workability. It is not much affected by the cement content if the water content per unit volume is constant.

3. Ambient humidity:-
The shrinkage increases with the decrease in humidity and the immersion in water causes expansion.

4. Type of aggregate:- The aggregate which exhibit moisture movement themselves and have low elastic modulus cause large shrinkage.

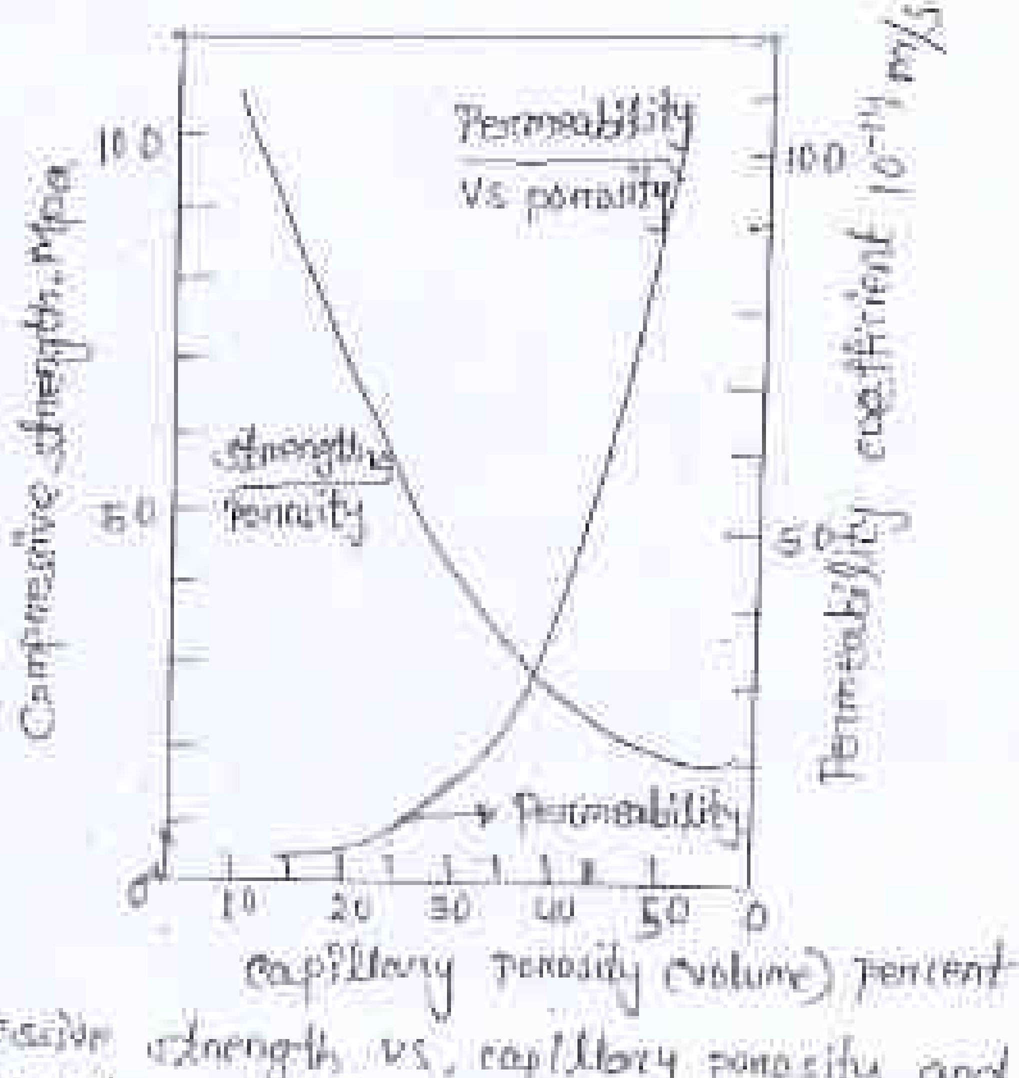
Creep of concrete :-

- The increase of strain in concrete with time under sustained stress is termed creep.
- The shrinkage and creep occur simultaneously a they are assumed to be additive for simplic
- When the sustained load is removed, the strain decreases immediatly by an amount equal to the elastic strain at the given age.
- This instantaneous recovery is then followed by a gradual decrease in strain, called creep recovery which is a part of total creep strain suffered by the concrete.
- If a loaded concrete specimen is viewed as being subjected to a constant strain, the creep decreases the stress progressively with time. This is called relaxation.
- The rate of creep decreases with time and the creep strains attained at a period of five years are usually taken as terminal values. while 80 to 85 percent shrinkage strains occur in six months only about 75 percent of creep strains occur in 12 months. All the factors which influence shrinkage influence creep also in a similar way.
- The types of aggregate, cement, and admixtures, entrained air, mix proportions, mixing time and consolidation, age of concrete, level of sustained stress, ambient humidity, temperature, and the size of the specimen are among the important factors influencing creep.

Permeability of concrete.

→ When excess water in concrete evaporates, it leaves voids inside the concrete element creating capillaries which are directly related to the concrete porosity and permeability.

→ The volume of moisture which may pass through the concrete depends on the permeability. Permeability is governed by porosity, which in turn is a direct consequence of the water-cement ratio of the concrete mix.



Compressive strength vs. capillary porosity and permeability co-efficient vs. capillary porosity.

→ By proper selection of ingredients and mix proportion and following the good construction practices almost impervious concrete can be obtained.

→ The magnified image of a slice of concrete indicates a well-graded aggregate mixts locked into a m... of hardened cement paste.

→ The well packed aggregate has reduced the amount of space to be filled by water and cement paste.

→ This has helped to improve the pore structure of concrete and hence its permeability.

The study of permeability of concrete is important for the following reasons

1. The penetration by materials in solution may adversely affect the durability of concrete. eg- $Ca(OH)_2$ leaches out and the aggressive liquid attack the concrete.

2. In case of reinforced concrete, ingress of moisture and air will result in corrosion of steel, and to cracking and spalling of concrete cover.

3. The moisture penetration depends on permeability and if the concrete can become saturated with water it is more vulnerable to frost action.

4. The permeability is also of interest in connection with water tightness of liquid retaining structures and the problem of hydrostatic pressure in the interior of the dams.

The flow of water through concrete is similar to flow through any porous body. The pores in cement paste consist of gel-pores and capillary pores in concrete as a result of incomplete compaction, are voids of larger size which give a honeycomb structure leading to concrete of low strength.

→ Such pores are not considered here. Since the capillary pores are larger in size than gel pores, and the cement paste is 20 to 100 times more permeable than the gel itself the permeability of cement paste is controlled by the capillary porosity of the paste.

→ In rocks the pores are fewer in number, but being of larger size they lead to higher permeability.

→ The permeability of cement paste also varies with the age of concrete on with the degree of hydration. with age, the permeability decreases because gel gradually fills the original water filled space.

→ For the pastes hydrated to the same degree, the permeability is lower with lower water-cement ratio on higher cement content.

→ For the same water-cement ratio the permeability of paste with coarser cement particles is higher than that with finer cement. In general, the higher the strength of cement paste, the lower will be the permeability.

→ A durable concrete should be relatively impervious. Permeability can be measured by a simple test, by measuring the quantity of water flowing through a given thickness of concrete in a given time. The drop in the hydraulic head using Darcy's equation is

$$\frac{dq}{dt} \times \frac{1}{A} = K \times \frac{\Delta h}{L}$$

where (dq/dt) is the rate of flow (ml/s). A the cross-sectional area (mm2). Δh-the drop in hydraulic head (mm) L the thickness of the sample in millimeters and K the coefficient of permeability (mm/s).

Durability of concrete:-

- A durable concrete is one that performs satisfactorily under anticipated exposure (working) conditions during its service life span.
- The materials and mix proportions used should be such as to maintain its integrity and, if applicable, to protect embedded metal from corrosion.
- Even though concrete is a durable material requiring a little or no maintenance in normal environment but when subjected to highly aggressive or hostile environments it has been found to deteriorate resulting in premature failure of structures or reach a state requiring costly repairs.
- One of the main characteristics influencing the durability of concrete is its permeability to the ingress of water, oxygen, carbon dioxide, chloride, sulfate and other potentially deleterious substances.
- As discussed in the previous section the permeability of concrete depends upon micro and macro-cracks, and voids developed during production and service.
- Most of the durability problems in the concrete can be attributed to the volume change in the concrete.
- Volume change in concrete is caused by many factors. The entire hydration process is nothing but an internal volume change, the effect of heat of hydration, the pozzolanic action, the sulfate attack, the carbonation, the moisture movement, all types of shrinkages, the effect of chlorides, corrosion of steel reinforcement and host of other aspects come under the preview of volume

change in concrete.

- The internal or external restraints to volume change in concrete results in the cracks.
- It is the crack that promotes permeability and thus it becomes a part of cyclic action, till such time that concrete deteriorates, degrades, disrupts and eventually fails.

Sulfate Attack:-

- Sulfate are generally found in ground water and sub-soil. Sea water also contains large quantity of sulfates.
- Sulfates can be naturally occurring or could be as a consequence of industrial waste disposal. Calcium, sodium, magnesium and ammonium sulfates (in order of hazard) are harmful to concrete as they can lead to increase in the concrete volume and consequent cracking.
- Calcium sulfate reacts with calcium aluminate present in cement hydrates forming an expansive ettringite.
- Sodium sulfate reacts with calcium hydroxide and forms expansive gypsum in presence of aluminates and may in turn lead to the formation of ettringite.
- Magnesium sulfate reacts with cement compounds decomposing the cement itself and subsequently producing gypsum and ettringite.

Selection of cement:

For minimizing the danger of sulfate attack, low C_3A content are recommended. Sulfate-resisting cement with very low C_3A content is mark suitable. However, if chlorides are also present the ground water and sub-soil in addition to sulfates then it is not recommended for theus in view of the vulnerability of low C_3A cement pastes to chloride ion diffusion.

- Blended cements are most preferred when both sulfates and chlorides are present in an environment at the same time.
- Blended cement have low C_3A content and also enable production of pastes containing small amount of calcium hydroxide. The pozzolana cements have also shown high sulfate resistance which is probably due to the composition and the structure of the pores in hydrated pastes.
- The resistance of concrete to sulfate attack can be tested by storing the specimens in a solution of sodium or magnesium sulfate or in a mixture of these two.

Type of cement	Chemical resistance of sulfates		
	Moderate	High	very high
	Limits of compound percent		
Ordinary Portland cement	$C_3A < 8$	$C_3A < 5$ $(2C_3A + C_4AF) < 25$ or $(C_4AF + C_2F) < 25$	$C_3A = 0$ $C_4AF < 20$ or $(C_4AF + C_2F) < 2$
Pozzolana cement	No special prescription	$C_3A < 6$	$C_3A < 3.5$
Slag cement	slag > 36	slag > 70	slag > 70 or $C_3A < 2$

Chloride Attack on concrete structures:-

-> Chloride ion (Cl-) is form when the element chlorine gains an electron or when a compound such as hydrogen chloride is dissolved in water.

-> High concentrations of chloride ions in concrete can be very problematic due to its electro-chemical nature chloride ions break down the passive layer of reinforcing steel, without the need to drop the pH level.

-> Corrosion takes place as the chloride ions react with the steel and the surrounding passive material to produce a chemical process which forms hydrochloric acid. The hydrochloric acid eat away at the steel reinforcement and thus leads to concrete cracking, spalling and eventually failure.

-> There are two main sources of chloride ions, 1st from the concrete mix components and the other from the surrounding environment. The first could come from unwashed aggregates and sand, admixture and even from the use of seawater in the concrete processing.

-> The second comes mainly from being exposed to marine environment such as sea salt spray direct seawater wetting, when concrete is a contact with soils which with chlorides deposits, or it can come from deicing salts and use of chemicals. It is by the process of diffusion that chlorides penetrates the concrete.

Damages Associated with chloride attack.

→ The main problem involving the corrosion of the steel is the spalling of the concrete cover. The oxide resulting from the corrosion is very porous and takes up to 10 times the volume of the steel which cause the break up of the concrete.

→ There are two types of concrete cracks that can be observed. Horizontal cracks occur in the rebar/concrete interface due to the oxide formation and leads to loss of the concrete cover. Vertical cracks occur when the tensile strength of the steel is exceeded. Also, if they are large enough, the cracks may accelerate the corrosion process by allowing access of corrosion agents.

→ If rust stains are observed around cracks and spalls these are indicative of chloride attack. When inspecting an exposed corroded reinforcement, it will typically show black coloured rusting and pitting of the steel where the aggressive hydrochloric acid has eaten away the reinforcing.

Prevention of chloride attack

For new structure, there are several methods of prevent or reduce chloride attack

* Increase concrete cover (min 50mm)
* Use epoxy coated rebars.
* Use stainless steel rebars.
* Cathodic protection.
* Use low water/cement ratio.
* Apply of anti-carbonation concrete coating.

for existing structure suffering from chloride attack the following repair methods can be applied.

* Apply of anti-carbonation concrete coating to slow down the corrosion process.
* Use of common inhibitors
* Install a cathodic protection system.
* In the case of extensive spalling of section loss a comprehensive concrete repair or a section replacement will be required.

Fire resistance

→ In general, concrete has good properties with respect to fire resistance, i.e the period of time under fire during which concrete continues to perform satisfactorily is relatively high and no toxic fumes are emitted.

→ The length of time over which the structural concrete preserves structural action is known as fire rating. Under sustained exposure to temperature in excess of 35°C along with the condition that a considerable loss of moisture from concrete is allowed leads to decrease in strength and in modulus of elasticity. The loss of strength at higher temperature is greater in saturated than in dry concrete.

→ Excessive moisture at the time of fire is the primary cause of spalling. In general moisture content of concrete is the most important factor determining the structural behaviour at higher temperature

→ Leaner mixes appear to suffer a relatively lower loss of strength than rich ones. Flexural strength

- The loss of strength is considerably lower when the aggregate does not contain silica, e.g. concrete made with limestone, crushed brick and blast-furnace slag aggregate.
- Low conductivity of concrete improves its fire resistance and hence a lightweight concrete is more fire resistant than ordinary concrete.
- The calcined material aggregate having a low density leads to a good fire resistance of concrete. Due to endothermic nature of carbonate aggregate during calcination at high temperature, heat is absorbed and further temperature rise is delayed. For example, dolomite gravel leads to a good fire resistance of concrete.

Concrete Mix design — New chapter

→ Concrete of different qualities can be obtained by using its constituents, namely cement, water, fine and coarse aggregates, and mineral additives, in different proportions.

→ Also the ingredients of widely varying characteristics can be used to produce concrete of acceptable quality.

→ The common method of expressing the proportions of the materials in a concrete mix is in the form of parts, or ratios of cement, the fine and coarse aggregates with cement being taken as unity. For example, a 1:2:4 mix contains one part of cement, two parts of fine aggregate and four parts of coarse aggregate.

→ The amount of water, entrained air and admixtures are any some expressed separately. The proportion should indicate whether it is by volume or by mass. The water cement ratio is generally expressed by mass.

→ The amount of entrapped air in concrete is expressed as a percentage of the volume of concrete. The amounts of admixtures are expressed as a percentage of the volume of concrete. The amounts of admixtures are expressed relative to the weight of cement.

→ Other forms of expressing the proportions are by ratio of cement to the sum of fine and coarse aggregate, i.e. aggregate cement ratio and by cement factor or number of bags of cement per cubic meter of concrete.

> The wide use of concrete as construction material has led to the use of mixes of fixed proportions which ensure adequate strength. These mixes are known as nominal mixes.

> These offer simplicity and under normal circumstances, have a margin of strength above that specified. However, these do not account for the varying characteristics of the constituents and may result in under or over rich mixes. Generally, a nominal mix is expressed in terms of aggregate - cement ratio.

> Nominal mix concrete may be used for concrete of grade M_{20} or lower. ~~The proportions of materials~~ These mixes called standard mixes are by definition conservative, but are useful as off the shelf sets of proportion that allow the desired concrete to be produced with minimum preparatory work.

> For example, for M_{15} grade concrete the proportion is 1:2:4 for the ordinary concrete from which quite undemanding performance is expected, the nominal or standard mixes may be used.

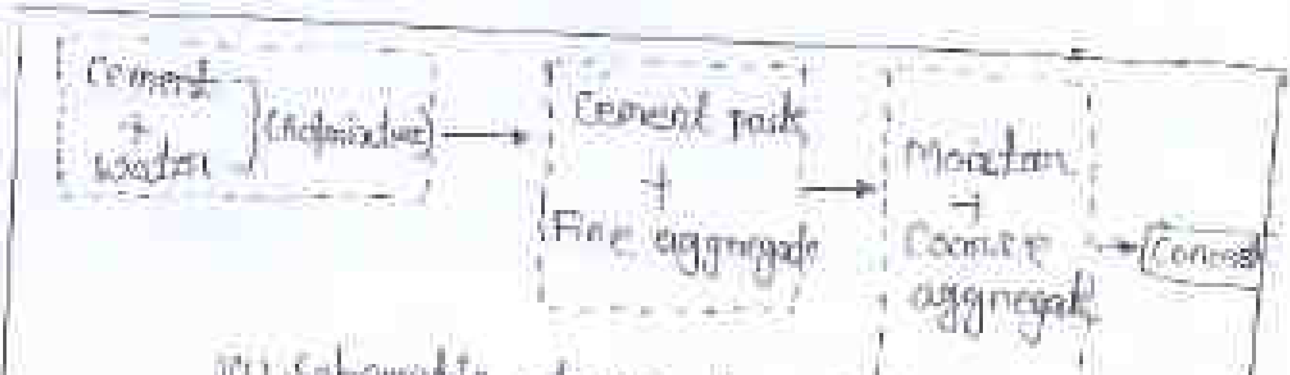
> The concrete making materials being essentially variable result in the production of mixes of variable quality. In such a situation, for high performance concrete, the most rational approach of mix proportioning is to select proportions with

specific materials in mind which possess more or less unique characteristics. This will ensure the concrete with the appropriate properties to be produced most economically. Other factors like workability, durability, compaction available, curing methods adopted etc. also influence the choice of the mix proportions.

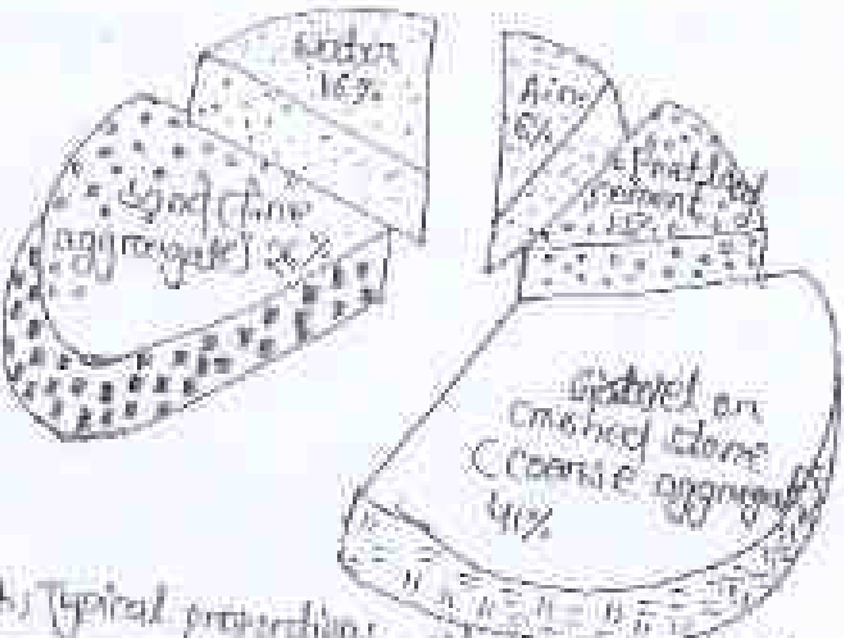
→ The mix proportion so arrived at is called designed mix. However, the method does not guarantee the correct mix for the designed strength, thereby necessitating the use of trial mixes.

→ In the process of mix proportioning, a number of subjective decisions are required on which hinge the important ramifications for the concrete.

→ The designed mix serves only as a guide. For many works it is desirable to go through the process of mix design, for example, where a large volume of concrete is required, a minimization of the cement content may reduce the cost appreciably, or where for technical reasons the type of concrete required necessitates careful selection and proportioning of ingredients.



(a) Schematic stages of concrete production from constituents



(b) Typical proportions of constituents for concrete mix.

Typical composition (Proportions of constituents) of concrete mix.

Proportions of nominal mix concrete

Grade of concrete	Total quantity of dry aggregate per bag of cement of 50 kg (kg)	Maximum water content per bag of cement of 50 kg (Litre)	Proportions of fine aggregate to coarse aggregate by mass
M10	480	34	Generally 1:2 with upper
M15	350	32	limit as 1:1.5 and lower
M20	250	30	limit as 1:2.5

Basic considerations for concrete mix design :-

→ The concrete mix design is a process of selecting suitable ingredients for concrete and determining their proportions which would produce, as economically as possible, a concrete that satisfies the job requirements, i.e., concrete having a certain minimum compressive strength, workability and durability.

→ The proportioning of the ingredients of concrete is an important phase of concrete technology as it ensures quality and economy.

→ The proportioning of concrete mixes is accomplished by the use of certain empirical relations which afford a reasonably accurate guide to select the best combination of the ingredients so as to achieve the desired properties. The design of plastic concrete of medium strengths can be based on the following assumptions :-

1. The compressive strength of concrete is governed by its water cement ratio.
2. For the given aggregate characteristics, the workability of concrete is governed by its water content.

• For high-strength or high-performance concrete mixes of low workability, considerable interactions between the above two criteria and the validity of such assumptions may become limited.

→ Moreover, there are various factors which affect the properties of concrete, e.g. the quality and quantity of cement, water and aggregates, techniques used for batching, mixing, placing, compaction and curing etc.

→ Therefore, the specific relationships used for batching, mixing, placing, compaction and curing etc. in the proportioning of a concrete mix should be considered only as a basis for making an initial guess at the optimum combination of the ingredients and the final mix proportion is obtained only on the basis of further trial mixes.

Factors influencing the choice of mix proportions:-

According to IS: 456-2000 and IS: 1343-1980, the design of concrete mix should be based on the following factors

1. Grade designation
2. Type and grade of cement
3. Maximum nominal size of aggregates.
4. Grading of combined aggregates.
5. Water cement ratio.
6. Workability.
7. Durability
8. Quality control.

Grade designation:-

→ The grade designation gives characteristic compressive strength requirements of the concrete.

→ As per IS: 456-2000, the characteristic compressive strength is defined as that value below which not more than five percent of the test results are expected to fall.

→ It is the major factor influencing the mix design.

→ Depending upon the degree of control available at the site, the concrete mix has to be designed for a target mean compressive strength which is somewhat higher than the characteristic strength.

Type and Grade of cement :-

→ The type of cement is important mainly through its influence on the rate of development of compressive strength of concrete.

→ The choice of type of cement depends upon the requirements of performance at hand.

→ Where very high compressive strength is required, e.g. in prestressed concrete railway sleepers, Portland cement of grades 43 and 53 conforming to IS: 8112-1989 and IS: 12269-1987, respectively, will be found suitable.

→ In situations where an early strength development is required, rapid-hardening Portland cement conforming to IS: 8041-1990 is preferable and for mass concrete construction, low-heat Portland cement conforming to IS: 12600-1989 is preferred.

→ The blended cements such as Portland-pozzolana cement and Portland slag cement are permitted for use in reinforced concrete construction.

→ While Portland slag cement is also permitted for prestressed concrete construction, the rate of development of early strength may be somewhat slower with blended cements.

→ A cement of consistent quality which exhibits minimum variation i.e, minimum standard deviation in the quality expressed in terms of its compressive strength makes it easier to determine the proportion of cement required to economical proportion of cement required to obtain a particular grade concrete mix only by changing the ratio of fine to coarse aggregate.

→ The currently available good brands of cement have been reported to maintain standard deviation as low as 2.5, 1.5 and 1.0 MPa, respectively for 33, 43 and 53 grades of cement. hence in the quality of cement IS: 12682-1942 has classified the cement grade-wise into six continuous ranges designated A to F, depending upon the 28 days compressive strength of the cement, i.e. A (32.5 - 37.5 MPa), B (37.5 - MPa), C (42.5 - 47.5 MPa), D (47.5 - 52.5 MPa), E (52.5 - 5 MPa) and F (57.5 - 62.5 MPa).

-> This classification covers the entire spectrum of strength. The strength of cement to be used in mix design computations is not the mean strength f_m of certain number of test results (say 'n') together be the characteristic strength f_{ck} &

$$f_{ck} = f_m - ks$$

where k is probability factor, a statistical parameter for not more than five percent test results to fall below the characteristic strength f_{ck} and s is standard deviation. For example, if the mean of 'n' compressive strength test results of a cement is 55, the cement would be apparently a grade 53 cement categorized as E (52.5 - 57.5 MPa.)

-> However, if the standard deviation of this particular cement is 4.0 mpa the characteristic strength would be:

$$f_{ck} = 55.0 - (1.65 \times 4.0) = 48.4 \text{ Mpa}$$

-> Thus the cement actually comes under grade 43, i.e. D category (47.5 - 52.5 MPa)

-> It is of prime importance to control the variation in quality of cement to the lowest minimum so that cement can be classified for highest grade.

-> If the 28-day compressive strength of cement is considered as an additional parameter influencing the relationship between water-cement ratio and 28-day compressive strength of concrete, the curves of can be used to make more precise estimate of water-cement ratio for the given grade of cement.

Maximum Nominal size of Coarse Aggregate:-

→ The maximum nominal size of the coarse aggregate is determined by sieve analysis and is designated by the sieve size higher than the largest size on which 15 percent or more of the aggregate is retained.

→ The maximum nominal size of the aggregate to be used in concrete is governed by the size of the section and the spacing of the reinforcement.

→ According to IS: 456-2000 and IS: 1343-1980, the maximum nominal size of the aggregate should not be more than one-fourth of the minimum thickness of the member, and it should be restricting to 5 mm less than the minimum clear distance between the main bars, or 5 mm less than the minimum clear cover to the reinforcement or 5 mm less than the spacing between the prestressing cables.

→ Within these limits, the nominal maximum size of the aggregate may be as large as possible, because larger the maximum size of aggregate, smaller is the cement requirement for a particular water cement ratio.

→ The workability also increases with an increase in the maximum size of the aggregate.

→ However, the smaller size aggregates provide larger surface area for bonding with the mortar matrix which increases the compressive strength and reduces the stress concentration in the mortar - aggregate interface.

→ For the concrete with higher water-cement ratio, the larger maximum size of aggregate may be beneficial whereas for high strength concrete, 10-20 mm size of aggregate is preferable.

Grading of combined aggregate :-

→ The relative proportions of the fine and coarse aggregates in a concrete mix is one of the important factors affecting the workability and strength of concrete.

→ For dense concrete, it is essential that the coarse and fine aggregates be well graded.

→ Continuous range of size of aggregate used in concrete.

→ In the concrete produced by using a well graded aggregate, smaller size particles and fill the voids between larger size particles, reducing the amount of space to be filled by water cement paste as illustrated where in magnified image of a piece of concrete shows a well graded aggregate mix locked into a matrix of hardened cement paste.

→ This results in improved strength, minimum shrinkage and lower cost of the concrete.

→ Generally, the locally available aggregates do not conform to the standard gradings.

→ In such cases, the aggregates need to be combined in suitable proportions so that the resultant (combined) grading approximates to a continuous grading close to the desired (or standard) grading.

→ The process of combining aggregates is aimed ~~at suitable proportions so that the resultant~~ obtaining a grading close to the coarsest grading of standard grading curves the most economical mix having highest permissible aggregate cement ratio.

→ IS : 383-1963 has recommended limits to the coarsest and finest gradings.

→ The aggregates can be combined by analytical calculations.

→ The method is easy to understand and calculations are trivial.

→ Consider two aggregates (designated as aggregate-I and aggregate-II) are to be combined.

→ Let α, β and γ represent the percentages of the combined (resultant) aggregate, aggregate-I and aggregate-II respectively, passing the seive corresponding to the point on standard grading curve taken as criterion that is the point to which the combined aggregate is required to approximate.

→ If x and y are the proportions of two aggregates in the combined state, then the condition that α percent of combined aggregate pass the criterion sieve results.

$$\beta x + \gamma y = \alpha(x+y)$$

$$\frac{x}{y} = \frac{\alpha-\gamma}{\beta-\alpha} = \frac{1}{K}$$

$$x:y = 1:K$$

$$K = (\beta-\alpha)/(\alpha-\gamma)$$

or, where,

→ Hence the two aggregate have to be combined in the proportions of 1:K.

→ The grading of the resulting combined aggregate is determined by first multiplying the grading of aggregate and aggregate by 1 and K respectively, then dividing the sum of corresponding products of the percentages passing the sive sizes by (1+K).

→ The values are rounded off to the nearest percentage.

Water-cement ratio:-

→ The compressive strength of concrete at a given age and under normal temperature depends primarily on the water-cement ratio lower the water-cement ratio greater is the compressive strength and vice versa.

→ A number of relationships between compressive strength and water-cement ratio are available which are supposed to be valid for a wide range of conditions.

→ In so far as the selection of the water cement ratio for the target compressive strength at 28 days concerned is applicable for both ordinary portland and portaland pozzolana cements with comparable validity.

→ the cement strength on grade specific relation between free water-cement ratio and 28 day compressive strength for cement of grades 33, 43 and 53.

→ However, the 28-day compressive strength of concrete is related to the 7-day compressive strength of cement mortar.

→ These relationships can also be used for the estimation of water-cement ratio.

→ For air-entrained concretes the compressive strengths are approximately 80 percent of that of air-entrained concretes.

→ The cement normally available have 7 days compressive strength between 17.5 MPa to 40 MPa. Thus depending upon the cement strength, an appropriate curve should first be chosen. The steps to be followed in selecting the water cement ratio are given below:-

1. The strength of cement to be used is determined. In India, only those type of cement are officially recognized, which give minimum seven-day strength of 22 MPa.
2. When cement strength data are available, the corresponding curve is chosen for the determination of water-cement ratio. In the absence of such data, the curve corresponding to cement strong of 22 MPa the minimum permissible as per the Indian standards may be used.

Workability :-

→ The workability of concrete for satisfactory placing and compaction is controlled by the size and shape of the section to be concreted, the quantity and spacing of reinforcement, and the method to be employed for transportation, placing and compaction of concrete.
→ The situation should be properly assessed to arrive at the desired workability. The aim should be to have the minimum possible workability consistent with satisfactory placing and compaction of concrete. It should be kept in mind that insufficient workability resulting in incomplete compaction may severely affect the strength, durabi

and surface finish of concrete and may thus prove to be uneconomical in the long run.

→ There is no rigid correlation between workability of concrete as measured by different test methods. It is desirable that for a given concrete, the test method be identified beforehand and workability be measure accordingly.

→ The workability measured by different test methods for comparable concrete ...

Durability :-

→ The durability of concrete can be defined and interpreted to mean its resistance to deteriorating influences which may reside inside the concrete itself, or to the aggressive environments.

→ The requirements of durability are achieved by restricting the minimum cement content and the maximum water-cement ratio to the values specified by the Ministry of Road Transport and Highways (MoRTH) IRC specifications for Road and Bridgeworks for bridges and by IS 456-2000 for other structures.

→ The permeability of cement paste increases exponentially with increase in water-cement ratio above 0.45 or so.

→ Thus from considerations of permeability, the water-cement ratio is usually restricted to 0.45 to 0.55, except in mild environments.

→ For a given water cement ratio, the cement content in the concrete mix should correspond to the required workability keeping in view the placing conditions and the concentration of reinforcement.

→ In addition, the cement content is chosen to ensure sufficient alkalinity to provide a passive environment against corrosion of steel e.g., in concrete for a marine environment or sea water minimum cement content of 250 kg/m³ or more is required.

→ Moreover, the cement content and water-cement ratio are so chosen as to provide a sufficient volume of cement paste to overfill the voids in the compacted aggregates.

→ The blended cements like portland pozzolana cement and portland slag cement render greater durability to the concrete in sulfatic environments and sea water.

→ Resistance to alternate freezing and thawing is not so important for Indian conditions but wherever situations demand, air entrained concrete could be employed using an air-entraining admixture. Air

→ Air entrainment lowers the compressive strength but increases workability which may permit certain reduction in the water content to make up the loss in compressive strength.

Minimum cement content, minimum water-cement ratio and minimum grade of concrete for different exposure conditions (MORTH: IRC Specifications of Road and Bridge Works - 2001)

For bridge with prestressed concrete or those with individual span lengths more than 30m or those that are built with innovative design/construction

Structural member	Min. cement content for all exposure conditions, kg/m³	Max. water cement ratio Exposure conditions		Min grade of concrete Exposure conditions	
		Normal	Severe	Moderate	Severe
(i) PCC members	360	0.45	0.45	M25	M30
(ii) RCC members	400	0.45	0.40	M35	M40
(iii) PSC members	400	0.40	0.40	M35	M40

(b) For bridge other than those mentioned in para (a) and for culverts and other incidental construction

Structural member	Min. cement content for all exposure conditions, kg/m³		Max. water cement ratio exposure conditions		Min. grade of concrete exposure conditions	
	Normal	Severe	Normal	Severe	Moderate	Severe
(i) PCC members	250	310	0.50	0.45	M15	M20
(ii) RCC members	310	400	0.45	0.40	M20	M25

Quality control:-

- The strength of concrete varies from batch over a period of time.
- The sources of variability in the strength of concrete may be considered due to variation in the quality of the constituent materials, variations in mix proportion due to batch process, variations in the quality of batching and mixing equipment available, the quality of supervision and workmanship.
- These variations are ~~available, the quality of supervision and workmanship~~ inevitable during production to varying degree.
- Controlling these variations is important in lowering the difference between the minimum strength and characteristic mean strength of the mix and hence reducing the cement content.
- The factor controlling this difference is quality control. The degree of control is ultimately evaluated by the variation in test results usually expressed in terms of the co-efficient of variation.
- It can be summarized that the aim of mix design is to obtain a most practical and economical combination of materials that will produce a concrete mix of necessary plasticity (workability) and, at the same time,

produce hardening concrete of required strength and durability.

→ Most of the mix design procedures are primarily based on the water-cement ratio law and absolute volume system of calculating the amount of materials.

→ As explained earlier, according to Abram's law the strength of fully compacted hardened concrete is approximately inversely proportional to the water content per cubic meter of cement, i.e. water-cement ratio.

→ The calculation of the quantities of the aggregates to be used with a given cement paste is based on the absolute volume method. The absolute volume of loose materials is the actual volume of the solid matter in all the particles ignoring the space occupied by the voids between the particles. absolute volume is

$$\text{Absolute volume} = \frac{\text{Mass of loose dry material}}{\text{specific gravity} \times \frac{\text{mass of unit volume of water}}{}}$$

general process

methods of concrete mix design for medium strength concretes:

→ Most of the available mix design methods are based on empirical relationships, charts and graphs developed from extensive experimental investigations. Basically they follow the same principles enunciated in the preceding section and only minor variations exist in different mix design methods in the process of selecting the mix proportions.

→ The requirements of the concrete mix are usually dictated by the general experience with regard to the structural design conditions durability and conditions of placing. Some of the commonly used mix design methods for medium strength concrete are the following:

1. Trial and adjustment method of mix design
2. British DOE mix design method.
3. ACI mix design method.
4. Concrete mix proportioning - IS Guidelines
5. Rapid method for mix design.

- The general step-by-step procedure for proportioning of concrete mixes is summarized below.

1- The maximum nominal size of the aggregate, which is economically available, is determined as per the specified requirements. The gradings of different size aggregates is determined. The proportions of different size aggregates to obtain a desired combined grading are determined.

2- The mean target strength is estimated from the specified characteristic strength and the level of quality control.

3- A suitable water-cement ratio to obtain a concrete mix of desired strength is selected from the generalized curves. The water-cement ratio so chosen is compared with that required for durability. The lower value is adopted.

4. The degree of workability in terms of slump, compacting factor or Vee-Bee time is selected as per job requirements. The water content for the required workability is computed.

5. The cement content is calculated and its quantity is checked for the requirements of durability.

6. The percentage of fine aggregate in the total aggregate is determined from the characteristics of coarse and fine aggregates. Alternatively, the aggregate cement ratio may be determined.

7. The concrete mix proportions for the first trial mix are computed and concrete cubes are cast in the laboratory as per standard procedure. After the required period of curing, the cubes are tested for the compressive strength of the mix.

8. The trial batches, obtained by making suitable adjustment in water-cement ratio or aggregate-cement ratio or in proportions of cement, sand and aggregate, are tested till the final mix composition is arrived at.

9. The final proportions are expressed either on mass or volume basis.

→ Most of the available mix design methods are essentially based on the above procedure and due consideration should be given for the moisture content of aggregate and the entrained air.

Trial and adjustment method of mix design :-

→ The trial and adjustment method is based on experimental approach and aims at producing a concrete mix which has minimum voids and hence is maximum density. The fine aggregate is mixed in sufficient quantity to fill the voids in the of coarse aggregate and cement paste is used in in sufficient quantity to fill the voids of aggregate which gives maximum mass of voids in mixed aggregate.

→ The proportion of fine to coarse aggregate which gives maximum mass of combined aggregate can be obtained by trials.

→ The process consists of filling a container of known volume with the two materials in thin layers, the fine being placed over the coarse aggregate and lightly rammed at each layer.

→ If the container is shaken too much the coarse aggregate will try to come on the top and the fine aggregate will deposit at the bottom without filling the voids of the coarse aggregate.

→ Since the density of the particles of fine and coarse aggregates is nearly the same, the mixture giving maximum weight will have maximum solid matter and hence least voids.

→ Such a combination will need the least amount of cement per cubic meter of concrete includes be most economical for given water-cement and slump.

→ In an alternate trial mix method, sand is combined with the coarse aggregate in several proportions such as 20:80, 30:70, 40:60, 50:50 and 60:40 and for each such mixture the quantity of cement per unit of a certain water-cement ratio per unit volume of concrete is determined to give the required workability (expressed in terms of slump).

→ The percentage of sand corresponding to the minimum cement is termed optimum.

→ A ratio requiring more cement will be needed to have the same consistency.

→ On the other hand, a smaller quantity of sand will make the mix harsh unless more cement is used for proper consistency. percentage of sand is optimum.

→ The optimum water-cement ratio, the step is lower for a low workability mix proportioning is as by step procedure of mix proportioning.

Follows:

1. The target mean compressive strength is determined from the characteristic strength.

2. The water-cement ratio is chosen for the target mean strength computed in step 1. The water-cement ratio so chosen is checked against limiting water-cement ratio for the requirements of durability and the lower of the two values is adopted.

3. The workability is determined in terms of the slum required for a particular job.

4. The maximum nominal size of the coarse aggregate that is available or desired to be used is determined.

5. The fine and coarse aggregates are so mixed that either the weight per liter of mixed aggregate is maximum or the sand percentage corresponds to the optimum value.

6. By actual trials the quantity of cement (in the form of cement paste) required per unit volume of aggregate to give the desired slump is determined.

7. The proportions of cement, fine aggregate, coarse aggregate and water to meet the requirements of strength, durability, workability and economy are computed and concrete cubes are cast and tested after the required period of curing for the compressive strength.

8. The trial mix is adjusted, if necessary, by varying the water-cement ratio or the aggregate-cement ratio to suit the actual requirements of the job.

Design Parameters :-

Target consistence (workability) of fresh concrete EN 206 permits specification by slump class or the normal working range i.e. zero slump to 200 mm slump and by other test methods. where consist-ence other than slump is specified. It is recommended that a relationship between the two is established

Characteristic compressive strength :-

- As discussed earlier, EN 206 classifies strength in terms of 28 day characteristic strength on the basis of cylinders and cubes e.g. C25/30 where the first number is the strength of a 150 mm (diameter) x 300 mm (height) cylinder and the second number is the 150 mm cube strength.
- However, it should not be presumed that by giving both cube and cylinder strengths a particular relationship is being assumed for purpose of conversion for concrete design or control.
- The strength margin factor and the standard deviation can be used for calculation of the target mean corresponding to the strength specified and the degree of safety required to take account of the conformity rules stipulated in EN : 206 for strength and for production control. It should be noted that the appropriate margin factor and standard deviation for cylinders may differ from those for cubes.

Design for tensile strength:-

Design for tensile strength can be performed on the basis of compressive strength by first determinige the relationship between tensile and compressive strength from concrete trails. The relation is generally material sensitive.

Target air content of fresh concrete:-

→ For non-air entrained concrete, air content is not specified but entrapped air is as use considered is design for EN-206 concrete. For air entrained concrete, EN-206 specifies minimum total air content with a maximum total air content is being four percent higher than the specified minimum.

Minimum target cement content and maximum target water/cement ratio:-

→ EN-206 requires specification of minimum cement and minimum water-cement ratio based on durability considerations which include a set of exposure classes related to different mechanisms of deterioration.

→ The main classification with the exception of X0 each class of expose is split into a number of subclasses.

→ In practice, there will always be one and in many cases, more than one relevant exposure class.

Exposure class X0 exists on its own and there are no requirements for the water-cement ratio or the minimum cement content.

→ The exposure classes and resistive measures list will provide the planner and designer a po rapidly usable basis for identifying relevant exposure classes.

→ An exposure class which requires the greatest resistance in the form of the lowest water-cement ratio along with the highest minimum cement content and the highest concrete strength class is selected. However, the minimum cement contents are independent of the type of cement used. EN:206 specifies design margins in the minimum cement content of minus 10 kg and in maximum water-cement ratio plus 0.02 in trial batch tests.

Additions (admixtures):-

EN:206 contains provisions for the use of Type-1 (nearly inert) additions and type 2 (pozzolanic or latent hydraulic) additions. The effect of additions on water demand, strength and on the restrictions placed upon their use in specifications is taken into account. EN:206 specifications for durability allow to count the proportion (k) of addition in the combination with cement towards satisfying specified limits for minimum cement content and maximum water-cement ratio. Here, the addition k called the efficiency or strength factor of the addition refers to relative strength of addition with respect to the cement. Some additions are allowed to be counted fully towards durability provided special tests of the combination have been made.

Mean size of Aggregate:-

A new series of standard sieve sizes for calculating mean sizes of aggregate for concrete has been recommended. The designations are established from the nominal lower and upper sieve sizes for the particular aggregates, the lower size being stated first. For example, an aggregate of maximum nominal size of 10mm, is designated as 4/10. The maximum aggregate sizes recommended are 10mm, 20mm and 40mm.

Procedure for concrete Design:

The method is suitable for the design of normal concrete having 28-day compressive strength as high as 75 MPa for non-air-entrained concretes. The method is also suitable for the design of concretes containing pulverized-fuel ash (fly ash) and GGBFS. The concrete design is carried out in the following six steps described in the flowchart given in fig.

1) Selection of free water cement ratio

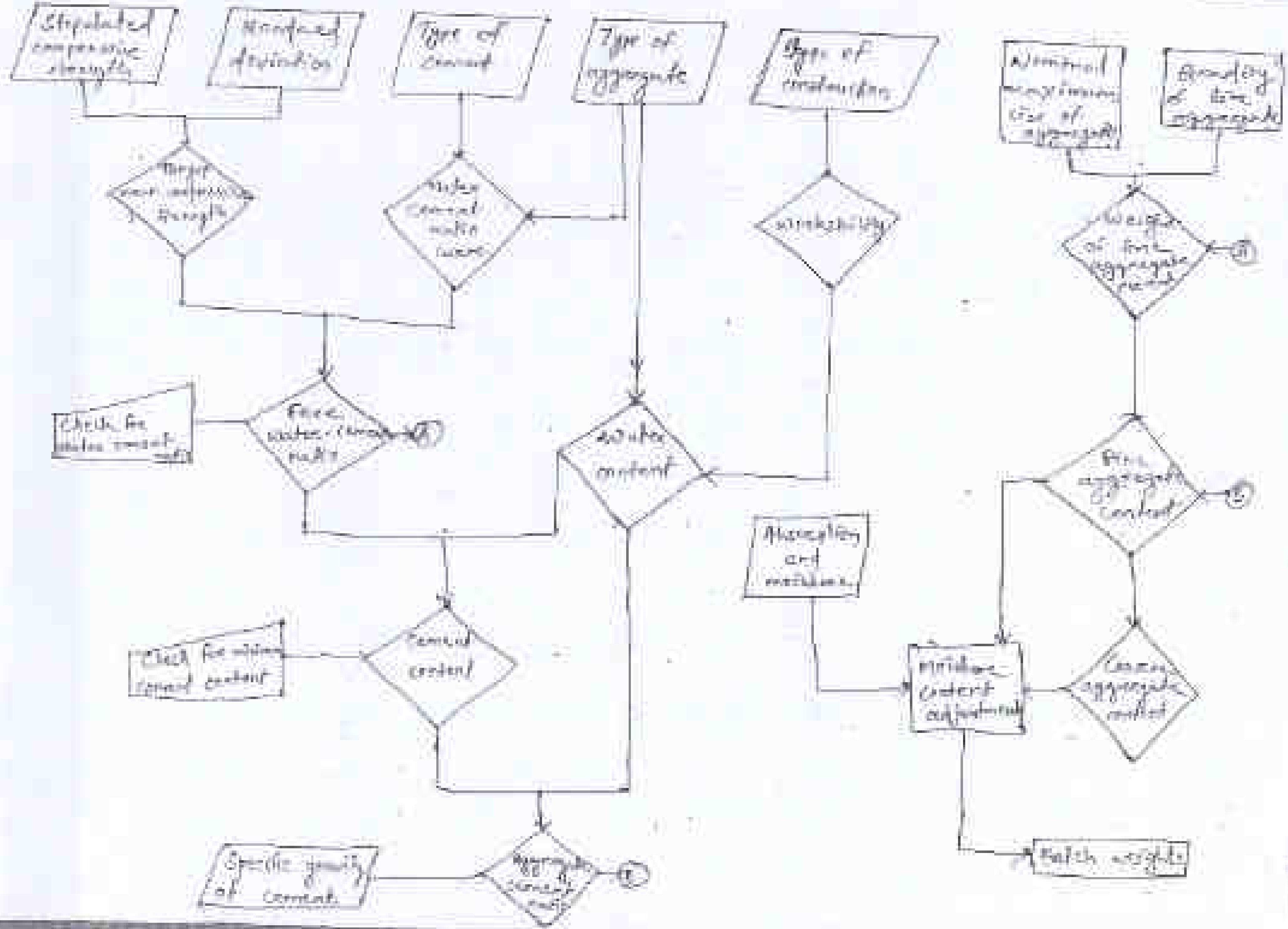
a) The target mean strength is obtained by adding a margin to the stipulated characteristic strength. The margin is either specified or calculated for a given proportion of defectives, and statistical standard deviation.

(b) If air entrainment is specified, the artificially raised modified target mean strength is calculated.

(c) The maximum free water-cement ratio is either specified or selected which will provide the target mean strength for concrete made from the given type of coarse aggregate and cement.

The procedure is as follow :-

For the given type of cement and aggregate, the compressive strength at the specified age corresponding to the reference water-cement ratio 0.50 is obtained from Table 10.15. For example when normal portland cement and uncrushed aggregate are used, the compressive strength is 42 MPa at 28 days. With this pair of data (42 MPa and water-cement ratio = 0.50) as a controlling.



Stipulated compressive strength
Standard deviation
Type of cement
Type of aggregate
Type of construction
Nominal maximum size of aggregate
Grading of fine aggregate
Workability
Water content
Check for water cement ratio
Cement content
Check for minimum cement content
Coarse aggregate content
Mixture content adjustment
Batch weights
Specific gravity of cement

1) Establishing common goal

Incompatible goal may be a major reason for the development of conflict. The main strategy of reducing the conflict should be to find common goals upon which the groups can agree and establish valid communication between the groups.

2) Reduction in Interdependence

Interdependence may be the main reason for inter-group conflict among the line and staff managers. The less is the interdependence, the less will be the amount of conflict among them.

3) Trust and communication

When the trust among the employees increase, then there will be more open and honest communication. The trust makes the individuals and groups to communicate openly with each other, so that the misunderstanding can be removed. They are encouraged to understand the problems of each other whenever necessary.

4) Co-ordination :-

Co-ordination is an important step for reducing the conflict and also it is the next step after communication. A proper co-ordination activity can reduce the conflict. If there is a good coordination among the employees, then they will be able to solve the problems themselves and help each other.

5) Use of superior authority

When the conflict can't be resolved by two organizational members or by two groups, it should be referred to a common superior who will resolve the conflict to ...