UNIT –I

Objective: To understand the basic concepts about manufacturing of cement, different grades of cement, physical and chemical requirements, various tests that perform on cement and various admixtures that are used in addition to cement.

Syllabus: Portland cement – Chemical composition – Hydration, Setting of cement,Fineness of cement, Structure of hydrated cement – Test for physical properties–Different grades of cements – physical and chemical requirements of OPCfor different grades of cement, Uses of cement. Admixtures – Mineral andchemical admixtures – accelerators, retarders, plasticizers, super-plasticizers, fly ash and silica fume.

Learning Outcomes:

Student will be able to

- Explain what cement was and its chemical composition
- Perform tests for physical properties of cement
- Explain physical and chemical requirements of OPC
- List out the uses of cement
- Explain various types of admixtures

Learning Material

ORDINARY PORTLAND CEMENT (OPC)

Cement is a fine grey powder which when reacted with water hardens to form a rigid chemical mineral structure which holds the aggregates together acting as glue and gives concrete its strengths. There are different types of cement depending on their composition, method of manufacturing (grinding, burning, etc.) and also the relative proportion of the different compounds. One of these types and the most commonly used one is Portland cement, which in turn is divided into many types. The other common type of cement is Portland pozzolana cement which contains some amount of pozzolanic materials.

Portland cement is one of the most widely used cement and is the most important hydraulic cement. It can also be used for mortar & plaster production. It is used in all types of structural concrete like walls, floors, bridges, tunnels, etc. It is further used in all types of masonry works like foundations, footings, dams, retaining walls, and pavements. When Portland cement is mixed with sand and lime, it serves as mortar for laying brick and stone; and when it is mixed with coarse aggregate and fine aggregate (sand) together with enough water, to ensure a good consistency, we get concrete.

Modern Portland cement is made from materials which must contain the proper proportions of lime (CaO), silica (SiO_2), alumina (Al_2O_3), iron (Fe_20_3) with minor amounts of magnesia and sulphur trioxide. A typical composition of general purpose Ordinary Portland cement is shown in the Table1.

Chemical Name	Chemical formula	Shorthand Notation	Weight percentage
Tricalcium silicate	$3CaO.SiO_2$	C_3S	55
Dicalcium silicate	$2CaO.SiO_2$	C_2S	18
Tricalcium aluminate	$3CaO.Al_2O_3$	C_3A	10
Tetracalciumaluminoferrite	$4CaO.Al_2O_3.FeO_3$	C_4AF	8
Calcium sulphate dehydrate (gypsum)	$CaSO_4.2H_2O$	CSH_2	6

Of these compounds, C_3S and C_3A are mainly responsible for early strength of concrete. High percentages of C_3S (low C_2S) results in high early strength but also high heat generation as the concrete sets. The reverse combination, that is, low C_3S and high C_2S develops strength more slowly and generates less heat. C_3A causes undesirable heat and rapid reacting properties, which can be prevented by adding $CaSO_4$ to the final product.

Manufacturing of Portland cement:

The raw materials required for manufacture of Portland cement are calcareous materials, such as lime stone or chalk, and argillaceous materials such as shale or clay.

The process of manufacture of cement consists of grinding the raw materials, mixing them intimately in certain proportions depending upon their purity and composition and burning them in a kiln at a temperature of about to 1300 to 1500 ^{0}C, at which temperature, the material sinters and partially fuses to form nodular shaped clinker. The clinker is cooled and ground to fine powder with addition of about 3 to 5 % of gypsum. The product formed by using this procedure is Portland cement.

There are two processes known as “wet” and “dry” process depending upon whether the mixing and grinding of raw materials is done in wet or dry conditions. With a little change in above process we have the semi dry process also where the raw materials are ground dry and then mixed with about 10 to 14% of water and further burnt to clinkering temperature.

Dry process:

The dry process is different from the wet process in that it involves a pneumatic transport medium instead of the water. In the dry process, the limestone and shale/red mud are crushed in a Roller Mill. (The basic principle of operation for a Roller Mill involves feed entering the mill on a rotating table where the raw material is crushed as it passes under the heavy rollers which are on a fixed shaft.) An air current is passed through the mill which takes the crushed raw mix into a separator where a centrifugal force is in operation. The coarse particles are forced out of the air current and fall back on the rotating table to be recrushed. The finer particles flow out with the air current. The raw mix is then passed into a blending silo to allow homogeneity of the raw mix before it passed into raw meal storage silo. The transformation of raw meal into clinker is carried out by a dry process kiln. Attached to this kiln is a four stage cyclone pre-heater which is used to preheat the raw meal before entry to the kiln. As with the wet process kiln, the interior is lined with special types of heat resistant bricks and the material is burnt at approximately the same temperature. This flame is also generated by burning either coal or fuel oil through a special burner. The raw meal is pumped to the kiln via a weigh feeder for constant measurement and a series of chemical and physical changes take place until the material leaves the kiln as red hot clinker. The clinker is cooled by passing air through the clinker in a clinker cooler.

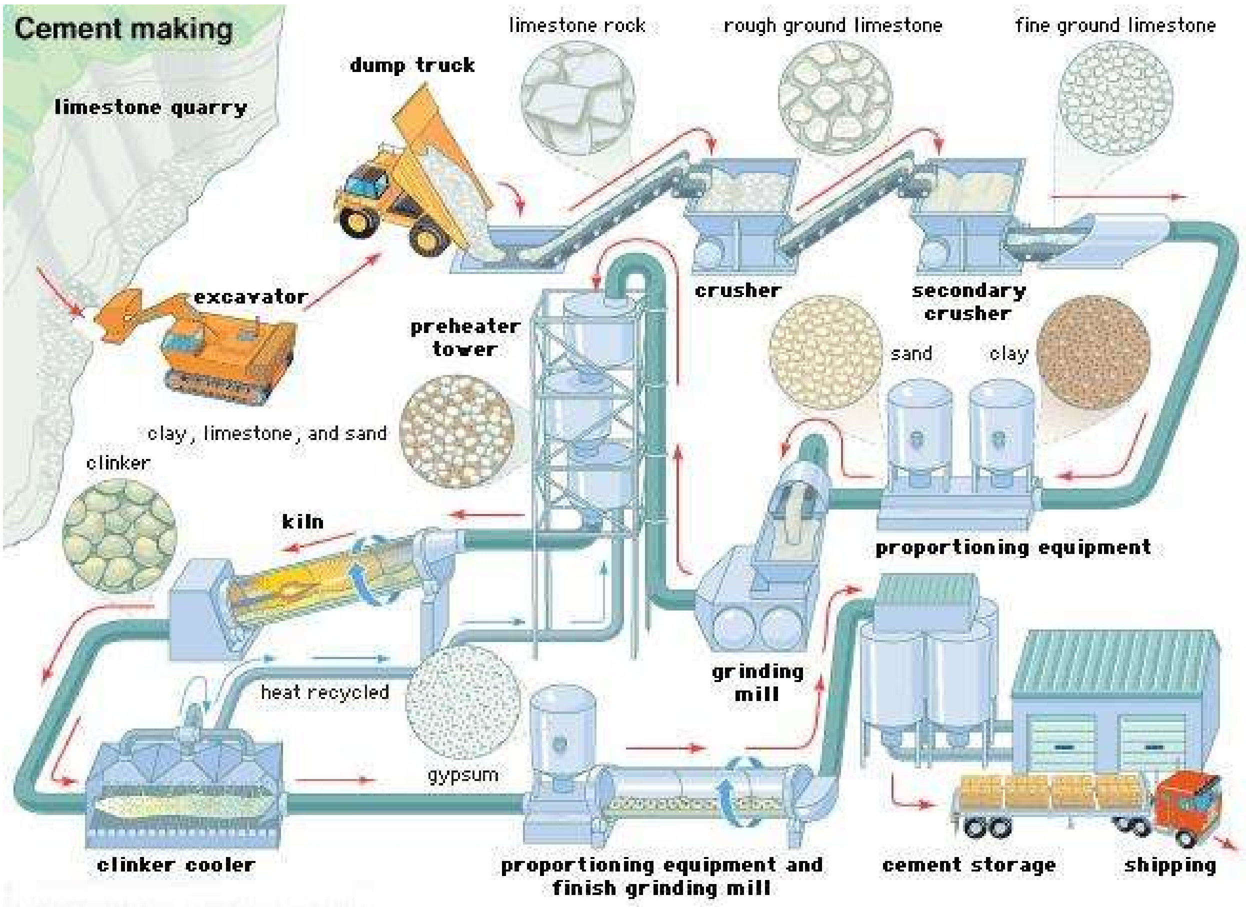


Fig 1.1: Diagrammatic representation of the dry process of manufacture of cement

Production of Cement

Clinker and gypsum are ground together in ball mills similar to the slurry grinding mills with the exception now that the operation is now dry grinding. These mills have three compartments and carry charges of assorted sizes of steel grinding media (balls) weighing about 100 tons for the smaller chamber and 600 tons in the larger chamber. Gypsum is added in order to regulate the setting time of the cement which would otherwise set almost immediately when mixed with water. The cement is ground to a fineness of not less than 3000 square cm. Per gram as determined by measurement of the specific surface.

Flow chart for manufacturing of cement by wet process:

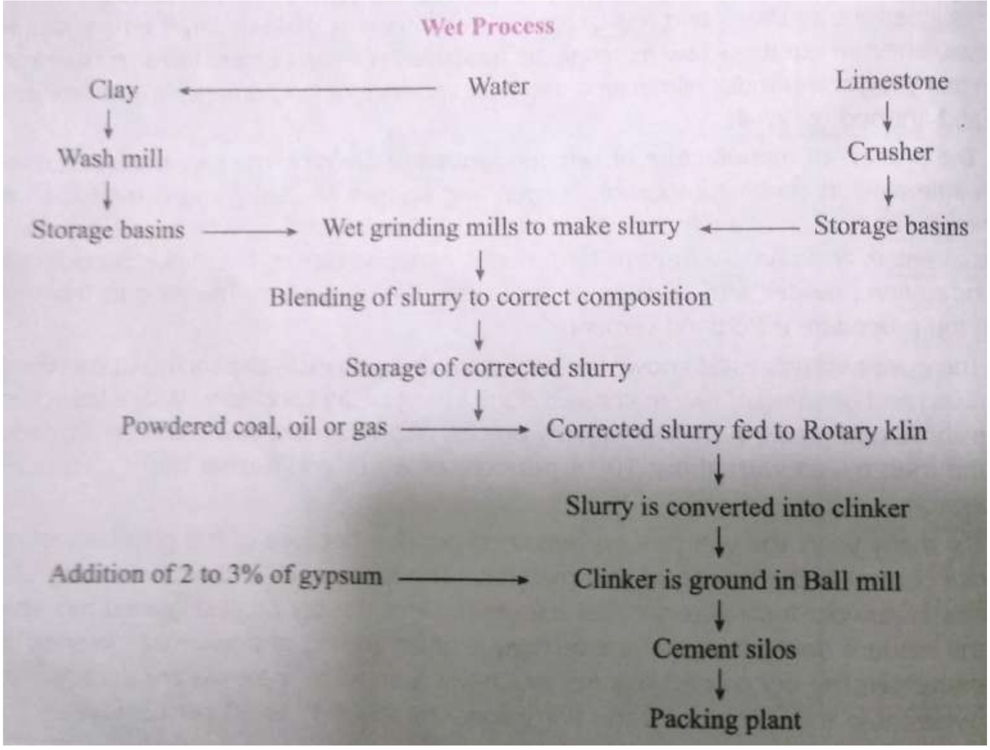


Fig 1.2

CHEMICAL COMPOSITION:

The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide. These oxides interact with one another in the kiln at high temperature to form complex compounds. The relative proportions of these oxide compositions are responsible for influencing the various properties of cement; in addition to rate of cooling and fineness of grinding.

Table 2.Shows the approximate oxide composition limits of raw material for ordinary Portland cement.

COMPOUND	Oxide	MASS %
Calcium oxide	**CaO**	**60-67**
Silicon dioxide	**SiO_2**	**17-25**
Aluminium oxide	**Al_2O_3**	**3-8**
Iron oxide	**Fe_2O_3**	**0.5-6**
Sulphate	**SO_3**	**1.3-4.5**
Magnesium oxide	**MgO**	**0.1-4**
Alkalies	**K_2O,Na_2O**	**0.4-1.3**

As mentioned earlier the oxides present in the raw materials when subjected to high clinkering temperature combine with each other to form complex compounds. The identification of major compounds is largely based on R.H. bogue's work and hence it is called "Bogue's Compounds". The four major compounds are listed in table 3.

Table 3: Bogue's Compounds

Chemical Name	Chemical formula	Short hand	Weight percentage

		Notation	
Tricalcium silicate	$3CaO.SiO_2$	C_3S	55
Dicalcium silicate	$2CaO.SiO_2$	C_2S	18
Tricalcium aluminate	$3CaO.Al_2O_3$	C_3A	10
Tetracalcium aluminoferrite	$4CaO.Al_2O_3.\ Fe_2O_3$	C_4AF	8
Calcium sulphate dehydrate (gypsum)	$CaSO_4.2H_2O$	CSH_2	6

It is to be noted that for simplicity's sake abbreviated notations are used. C stands for CaO, S stands for SiO2, A for Al2O3, F for Fe2O3 and H for H2O. The equations suggested by Bogue for calculating the percentages of major compounds are given below.

$C_3S = 4.07\ (CaO) – 7.60\ (SiO_2) – 6.72\ (Al_2O_3) – 1.43\ (Fe_2O_3) – 2.85\ (SO_3)$

$C_2S = 2.87\ (SiO_2) – 0.754\ (3CaO.SiO_2)$

$C_3A = 2.65\ (Al_2O_3) – 1.69\ (Fe_2O_3)$

$C_4AF= 3.04\ (Fe_2O_3)$

In addition to the four major compounds, there are many minor compounds formed in the kiln. Two of the minor oxides namely K_2O and Na_2O referred to as alkalis in cement are of some importance and Expressed in terms of Na_2O. These alkalis basically react with active silica in aggregate and produce what is called alkali-silica gel of unlimited swelling type under favorable conditions of moisture and temperature in voids and cracks and further it causes disruption and pattern cracking.

HYDRATION OF CEMENT:

When water and Portland cement are mixed, the constituent compounds of the cement and the water undergo a chemical reaction resulting in hardening of the cement. This chemical reaction of the cement and the water is called hydration, and it results in new compounds called hydrated products. The reaction of cement with water is exothermic. The reaction liberates a considerable quantity of heat. This liberation of heat is called HEAT OF HYDRATION. Both C_3S and C_2S react with water to produce an amorphous calcium silicate hydrate known as C–S–H gel which is the main glue, which binds the sand and coarse aggregate particles together in concrete.

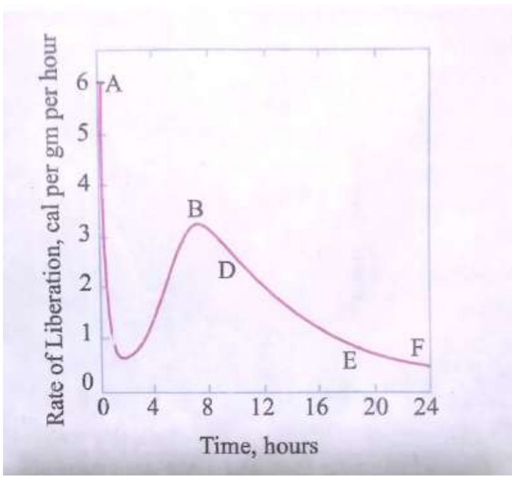


Fig1.3. Heat liberation from a setting time

Each of the compounds found in the cement react with water, but the rate at which they react is different. C_3S and C_3A are the most reactive compounds, whereas C_2S reacts much more slowly. Approximately half of the C_3S present in typical cement will be hydrated by 3 days and 80% by 28 days, in contrast, the hydration of C_2S does not normally proceed to a significant extent until approximately 14 days. Gypsum is added to lower the rate of hydration of C_3A.

The rate and amount of heat of hydration are affected by various factors. Among these cement composition and fineness, water to cement ratio of the concrete, age of the paste and ambient conditions are the most common ones. Varying the cement composition affects the rate of reaction because the different compounds present in the cement have different speed of hydration. The hydration of Portland cement as a whole is more complex than the individual compounds. This is because the different compounds have different products, reaction rate, and each of the compounds consumes water.

When cement is first mixed with water some of the added calcium sulphate, dissolve rapidly. The purpose of adding calcium sulphate is in order to retard the hydration of C_3A, which without calcium sulphate results in flash set due its high rate of reaction with water. This is because C_3A is more reactive than any of the compounds in the cement and if allowed will take much of the water. The order of reaction is $C_3A > C_3S >$

$C_4AF > C_2S$. But the rate of hydration of these compounds differs from cement to cement depending on the fineness, the rate of cooling of the clinker and other factors like presence of impurities and other cement compounds.

Structure of hydrated cement:

To understand the behavior of concrete, it is necessary to acquaint ourselves with the structure of hydrated hardened cement paste. If concrete is considered as two phase material namely, the paste phase and aggregate phase, the understanding of the paste phase becomes more important as it influences the behavoiur of concrete to a much greater extent.

Transition Zone: concrete is generally considered as two phase material i.e., paste phase and aggregate phase. At micro level it is seen that aggregate particles are dispersed in a matrix of cement paste. As the microscopic level, the complexities of the concrete begin to show up, particularly in the vicinity of large aggregate particles. This area can be considered as a third phase, the transition zone, which represents the interfacial region between the particles of coarse aggregate and hardened cement paste. Transition zone is generally a plane of weakness and, therefore, has a far greater influence on the mechanical behavior of concrete.

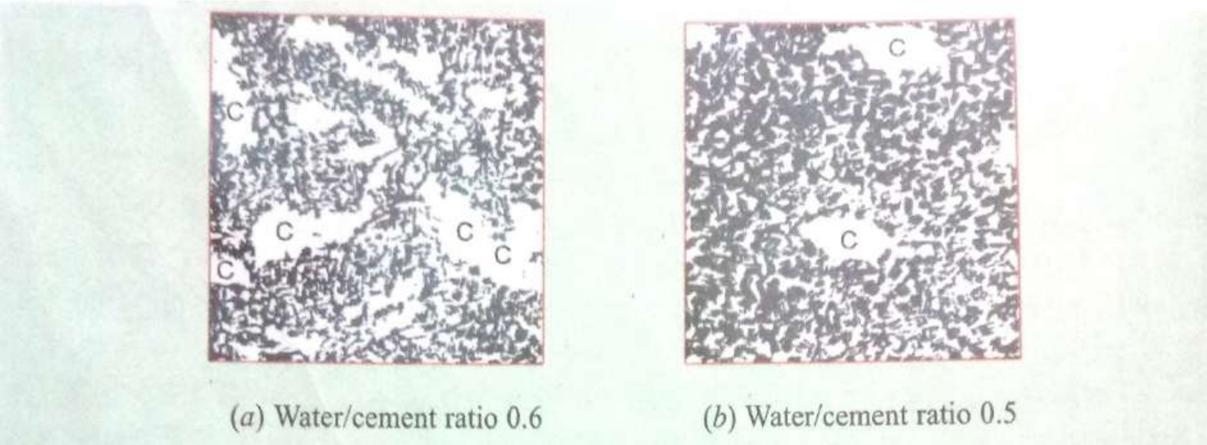


Fig. 1.4 diagram representing paste structure. c represents capillary cavities

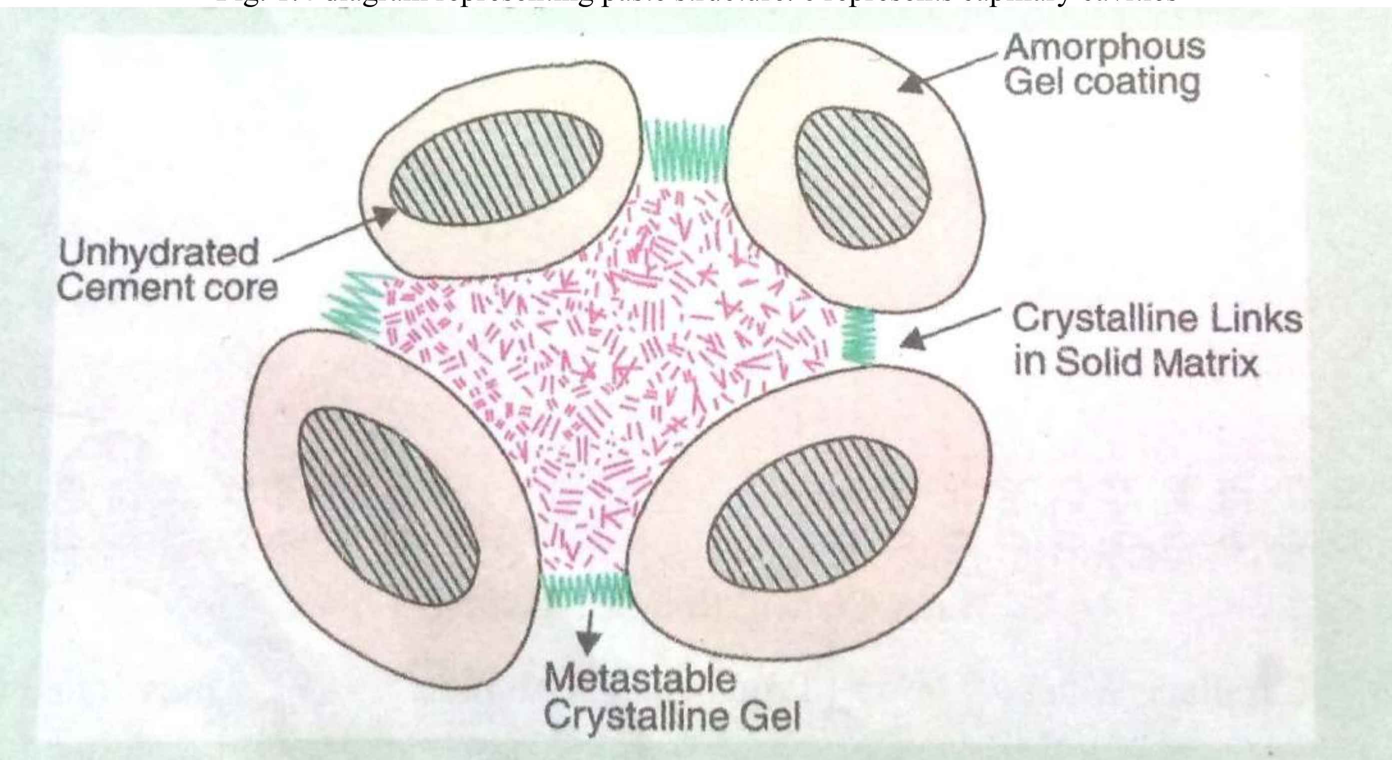


Fig. 1.5 Microscopic schematic model representing the structure of hardened cement paste

Fresh cement paste is a plastic mass consisting of water and cement. With the lapse of time, say one hour, the hardening paste consists of hydrates of various compounds, unhydrated cement particles and water. With further lapse of time the quantity of unhydrated cement left in the paste decreases and the hydrates of the various compounds increase. Some of the mixing water is used up for chemical reaction, and some water occupies the gel-pores and the remaining water remains in the paste. After sufficiently long time (say one month) the hydrated paste can be considered to be consisting of about 85 to 90% of hydrates of the various compounds and 10 to 15 per cent of unhydrated cement. The mixing water is partly used up in the chemical reactions. Part of it occupies the gel-pores and the remaining water unwanted for hydration or for filling in the gel-pores causes capillary cavities. These capillary cavities may have been fully filled with water or fully empty depending upon thr age and ambient temperature and humidity conditions. Figure 1(a) and (b) Schematically depict the structure of hydrated cement paste. The dark portion represents gel. The small gap within the dark portion represents gel-pores and big space such as marked "c" represents capillary cavities fig 2 represents the microscopic schematic model of hardened cement paste.

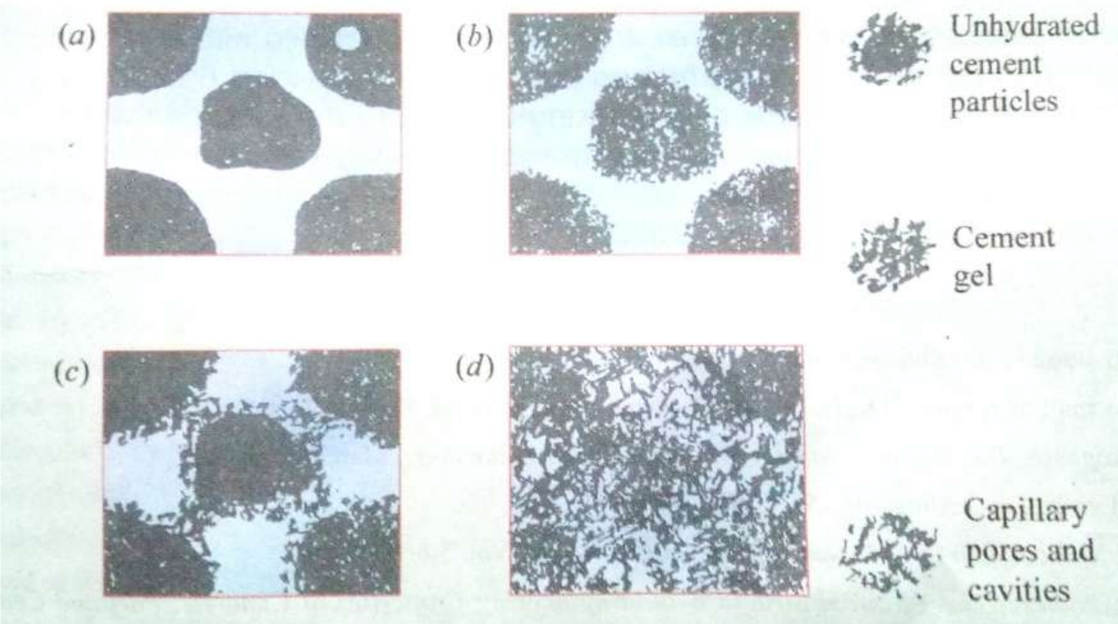


Fig.1.6 Diagrammatic representation of the hydration process and formation of cement gel

Water requirements for hydration:

It has been brought out earlier that C_3S requires 24% of water by weight of cement and C_2S requires 21% it has also been estimated that on an average 23% of water by weight of cement is required for chemical reaction with Portland cement compounds. This 23% of water chemically combined with cement and therefore, it is called bound water. A certain quantity of water is imbibed within the gel-pores. This water is known as gel water. It can be said that bound water and gel-water are complimentary to each other. If the quantity of water is inadequate to fill up the gel-pores, the formations of gel itself will stop and if the formation of gel stops there is no question of gel-pores being present. It has been further estimated that about 15 per cent by weight of cement is require to fill up the gel-pores. Therefore, a total 38 per cent of water by weight of cement is required for the complete chemical reactions and to occupy the space within gel-pores. If the water equal to 38 per cent by weight of cement is only used it can be noticed that the resultant paste will undergo full hydration and no extra water will be available for the formation of undesirable capillary cavities. On the other hand, if more than 38 per cent of water is used, then the excess water will cause undesirable capillary cavities. Therefore greater the water above the minimum required is used, the more will be undesirable capillary cavities. In all this it is assumed that hydration is taking place in a sealed container, where moisture to and from the paste does not take place.

What has been described briefly is the approximate structure of hardened cement paste on account of the hydration of some of the major compounds. Very little cognisance is taken of the product of hydration of the other major and the minor compounds in cement. The morphology of product of hydration and the study of structure of hardened cement paste in its entirety is a subject of continued research.

SETTING TIME OF CEMENT: Cement when mixed with water forms paste which gradually becomes less plastic, and finally a hard mass is obtained. In this process of 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 termed setting time. The time is reckoned from the instant when water is added to the cement.

- The setting is divided into two parts, namely, the initial and final setting times.
- The time at which the cement paste loses its plasticity is termed the initial setting time.
- The time taken to reach the reach the stage when the paste becomes a hard mass is known as the final setting time.

FINENESS OF CEMENT: The fineness of a cement is measure of the size of particles of cement and is expressed in terms of specific surface of cement. It can be calculated from particle size distribution or one of the air permeability methods. It is an important factor in determining the rate of gain of strength and uniformity of quality. For a given weight of cement, the surface area is more for a finer cement than for a coarsecement. The finer the cement, the higher is the rate of hydration,as more surface area is available for chemical reaction. This results in the early development of strength.

Fineness of cement is tested in two ways:

(i) By sieving.
(ii) By determination of specific surface (total surface area of all the particles in one gram of cement) by air permeability apparatus. Expressed as cm^2/gm or m^2/kg. Generally Blaine air permeability apparatus is used.

Sieve test: weigh correctly 100 grams of cement and taken it on a standard IS Sieve No.9(90 microns). Break down the air-set lumps in the sample with fingers. Continuously sieve the sample giving circular and vertical motion for a period of 15 minutes. Mechanical sieving devices may also be used. Weigh the residue left on the sieve. This weight shall not exceed 10% for ordinary Portland cement.

Tests for physical properties of cement

1. Fineness test
2. Standard consistency test
3. Initial setting time
4. Final setting time
5. Specific gravity of cement
6. Compressive strength of cement

Fineness Test: According to IS 4031-1968

Fineness is defined as the surface area of cement particles per unit weight, means more number of particles per unit weight. If the percentage of fineness is more than 90 % the cement is supposed to be fresh, if it is less than 90 % than that Cement should be avoided to use.

Standard consistency Test: According to IS 4031 (Part 4) 1988

The standard consistency of a cement paste is defined as that consistency which will permit the vicat plunger to penetrate to a depth of 5 to 7mm from the bottom of the vicat mould.

Initial Setting and Final Testing Time Test: According to IS 4031 (Part 5) 1988

The time period elapsed between the time of adding water to the cement to the time when the needle fails to pierce the mould for 5 + 0.5mm. The time period elapsed between the time of adding water to the cement to the time when the annular ring fails to make the impression on the mould is called the final setting time.

Specific Gravity Test:

Specific gravity is the ratio of the density of a substance compared to the density (mass of the same unit volume) of a reference substance. *Apparent* specific gravity is the ratio of the weight of a volume of the substance to the weight of an equal volume of the reference substance. The reference substance is nearly always water for liquids or air for gases.

Compressive Strength of Cement: According to IS 650-1991

Compressive strength of cement is determined from mortar cubes of size 7.07 X 7.07 X 7.07c.m and cement to sand ratio 1:3. The strength is obtained for 3,7,28 days. The strength obtained on 28th day is called compressive strength of cement.

DIFFERENT GRADES OF CEMENTS

The Ordinary Portland cement (OPC) was classified into three grades, namely 33 grade, 43 grade, 53 grade depending upon the strength of cement at 28 days when tested as per IS 4031-1988.

- If the 28 days strength is not less than 33 N/mm^2, it is called OPC 33 grade cement.

  33 Grade ordinary Portland cement conforming to IS 269-1989

- If the 28 days strength is not less than 43 N/mm^2, it is called OPC 43 grade cement.

  43 Grade ordinary Portland cement conforming to IS 8112-1989

- If the 28 days strength is not less than 53 N/mm^2, it is called OPC 53 grade cement.

  53 Grade ordinary Portland cement conforming to IS 12269-1987

TYPES OF CEMENTS

a) 33 Grade ordinary Portland cement conforming to IS 269-1989

b) 43 Grade ordinary Portland cement conforming to IS 8112-1989

c) 53 Grade ordinary Portland cement conforming to IS 12269-1987

d) Rapid hardening Portland cement conforming to IS 8041-1990

e) Portland slag cement conforming to IS 455-1989

f) Portland pozzolana cement (fly ash based) conforming to IS 1489 (Part 1)

g) Portland pozzolana cement (calcined clay based) conforming to IS 1489 (Part 2)

h) Hydrophobic cement conforming to IS 8043-1991

I) Low heat Portland cement conforming to IS 12600-1989

j) Sulphate resisting Portland cement conforming to IS 12330

Table 4

BELOW SHOWS DIFFERENT TYPES OF CEMENT, THEIR COMPOSITION AND USES:

TYPES OF CEMENT	COMPOSITION	PURPOSE
Rapid Hardening Cement	Increased Lime content	Attains high strength in early days it is used in concrete where form works are removed at an early stage.

Quick setting cement	Small percentage of aluminium sulphate as an accelerator and reducing percentage of Gypsum with fine grinding	Used in works is to be completed in very short period and concreting in static and running water
Low Heat Cement	Manufactured by reducing tricalcium aluminate	It is used in massive concrete construction like gravity dams
Sulphates resisting Cement	It is prepared by maintaining the percentage of tricalcium aluminate below 6% which increases power against sulphates	It is used in construction exposed to severe sulphate action by water and soil in places like canals linings, culverts, retaining walls, siphons etc.,
Blast Furnace Slag Cement	It is obtained by grinding the clinkers with about 60% slag and resembles more or less in properties of Portland cement	It can use for works economic considerations is predominant.
High Alumina Cement	It is obtained by melting mixture of bauxite and lime and grinding with the clinker it is rapid hardening cement with initial and final setting time of about 3.5 and 5 hours respectively	It is used in works where concrete is subjected to high temperatures, frost, and acidic action.
White Cement	It is prepared from raw materials free from Iron oxide.	It is more costly and is used for architectural purposes such as precast curtain wall and facing panels, terrazzo surface etc.,
Coloured cement	It is produced by mixing mineral pigments with ordinary cement.	They are widely used for decorative works in floors
Pozzolanic Cement	It is prepared by grinding pozzolanic clinker with Portland cement	It is used in marine structures, sewage works, sewage works and for laying concrete under water such as bridges, piers, dams etc.,
Air Entraining Cement	It is produced by adding indigenous air entraining agents such as resins, glues, and sodium salts of Sulphates etc during the grinding of	This type of cement is specially suited to improve the workability with smaller water cement ratio and to improve frost resistance of

	clinker.	concrete.
Hydrographic cement	It is prepared by mixing water repelling chemicals	This cement has high workability and strength
Quick setting cement	Small percentage of aluminium sulphate as an accelerator and reducing percentage of Gypsum with fine grinding	Used in works is to be completed in very short period and concreting in static and running water

Table. 5

PHYSICAL AND CHEMICAL REQUIREMENTS OF OPC FOR DIFFERENT GRADES OF CEMENT:

Physical Requirements of Ordinary Portland Cement(OPC):					
S.no	***Property***		***33 grade OPC (IS 269 – 1989)***	***43 grade OPC (IS 8112 – 1989)***	***53 grade OPC (IS 12269 – 1987)***
1.	Fineness(m^2/kg) min		225	225	225
2.	Soundness by	Le Chatelier (mm) Max.	10	10	10
		Autoclave (%) Max.	0.8	0.8	0.8
3.	Setting Time	Initial(min) Min.	30	30	30
		Final (min) Max.	600	600	600
4.	Compressive Strength	1 day (MPa) Min.	N S	N S	N S
		3 days (MPa) Min.	16	23	27
		7 days (MPa) Min.	22	33	37
		28 days (MPa) Min.	33	43	53
Chemical Requirements of Ordinary Portland Cement(OPC)					
1.	Lime saturation factor (%)	Min.	0.66	0.66	0.8
		Max.	1.02	1.02	1.02
2.	Alumina Iron Ratio (%)	Min.	0.66	0.66	0.66
3.	Insoluble Residue (%)	Max.	4	2	2
4.	Magnesia (%)	Max.	6	6	6
5.	Sulphuric Anhydride		2.5% Max. when C_3A is 5 or less 3% Max. when C_3A is greater than 5	2.5% Max. when C_3A is 5 or less 3% Max. when C_3A is greater than 5	2.5% Max. when C_3A is 5 or less 3% Max. when C_3A is greater than 5
6.	Loss on Ignition (%)	Max.	5	5	4

Lime Saturation factor percent:

USES OF CEMENTS:

1. It is used in mortar for plastering, masonry work, pointing, etc.
2. It is used for making joints for drains and pipes.
3. It is used for water tightness of structure.
4. It is used in concrete for laying floors, roofs and constructing lintels, beams, stairs, pillars etc.
5. It is used where hard surface is required for the protection of exposed surfaces of structures against the destructive agents of the weather and certain organic or inorganic chemicals.
6. It is used for precast pipes manufacturing, piles, fencing posts etc.
7. It is used in the construction of important engineering structures such as bridges, culverts, dams, tunnels, light houses etc.
8. It is used in the preparation of foundations, water tight floors, footpaths etc.
9. It is employed for the construction of wells, water tanks, tennis courts, lamp posts, telephone cabins, roads etc.

Admixtures:

Admixtures are those ingredients in concrete other than Portland cement, water, and aggregates that are added to the mixture immediately before or during mixing. About 80% of concrete produced in North America have one or more admixtures. About 40% of ready-mix producers use fly ash. About 70% of concrete produced contains a water-reducer admixture. One or more admixtures can be added to a mix to achieve the desired results.

The reasons to use admixtures are:

- Increase slump and workability;
- Reduce or prevent shrinkage;
- Modify the rate or capacity for bleeding;
- Reduce segregation;
- Improve pump ability and finish ability;
- Accelerate the rate of strength development at early ages;
- Decrease permeability of concrete;
- Increase strength(compressive, tensile, or flexural);
- Gas-forming;
- Foaming;
- Produce coloured concrete.

There are two main groups of admixtures.

1. Chemical admixtures
2. Mineral admixtures

Chemical admixtures

They reduce the cost of construction, modify the properties of concrete and improve the quality of concrete during mixing, transportation, placing and curing.

Some of the chemicals admixtures are:

1. **Air-entrainment**: Air entraining admixtures add microscopic air bubbles to theconcrete, enhancing its resistance to freeze/thaw cycles and makes the concrete easier to finish.
2. Water-reducing: Water reducers are used to reduce the amount of water requiredto produce a given slump. They also provide a ball bearing effect, making the concrete easier to finish, and produce better cement hydration.
3. Set-retarding: Set retarders have the opposite effect, slowing the set andenabling delivery to distant sites and finishing during hot weather.
4. Accelerating: Set accelerators speed the set-time of the mixture, enablingfinishing operations to begin sooner, useful during cold weather pours.
5. Plasticizers: These are additives that increase the plasticity or viscosity of a material.
6. Super-plasticizers: Super plasticizers, also known as high range water reducers, are chemical

admixtures used where well-dispersed particle suspension is required

7. Corrosion-inhibitors: A corrosion inhibitor is a chemical compound that, when added to a liquid or gas, decreases the corrosion rate of a material.

Mineral admixtures

These are inorganic materials that also have pozzolanic or latent hydraulic properties. These very fine-grained materials are added to the concrete mix to improve the properties of concrete (mineral admixtures), or as a replacement for Portland cement (blended cement).

- **Fly ash:** A by-product of coal-fired electric generating plants which is used to partially replace Portland cement (by up to 60% by mass). The properties of fly ash depend on the type of coal burnt. In general, siliceous fly ash is pozzolanic, while calcareous fly ash has latent hydraulic properties.
- **Ground Granulated Blast Furnace Slag (GGBFS or GGBS):** A by-product of steel production is used to partially replace Portland cement (by up to 80% by mass). It has latent hydraulic properties.
- **Silica Fume:** a by-product of the production of silicon and ferrosilicon alloys. Silica fume is similar to fly ash, but has a particle size 100 times smaller. This results in a higher surface to volume ratio and a much faster pozzolanic reaction. Silica fume is used to increase strength and durability of concrete, but generally requires the use of super plasticizers for workability.
- **Metakaolin:** Metakaolin produces concrete with strength and durability similar to concrete made with silica fume. While silica fume is usually dark gray or black in colour, metakaolin is usually bright white in colour, making it preferred choice for architectural concrete where appearance is important.

Assignment-Cum-Tutorial Questions

A. Questions testing the remembering / understanding level of students

I) Objective Questions

1. Before testing setting time of cement one should test cement for
   (a) Soundness (b) strength (c) fineness (d) consistency
2. For marine works, the best suited cement is
   (a) PPC (b) rapid hardening cement (c) OPC (d) blast furnace cement
3. Early gain of strength id due to
   (a) C_3A (b)C_3S (c) C_2S (d) C_4AF
4. Initial setting time of cement is due to reaction of
   (a) C_3A (b)C_3S (c) C_2S (d) C_4AF
5. keene's cement is made from
   (a) lime (b) slag (c) gypsum (d) pozzolana
6. Gypsum has
   (a) high bulk density (b) negligible shrinkage (c)damp proofing property (d) low creep
7. Snowcem is
   (a) powdered lime (b) chalk powder (c) mixture of a& b (d) coloured cement

8. Di- calcium silicate
   (a) hydrates rapidly (b) generates less heat (c) reacts with water only (d) hardens rapidly
9. When water is added to cement
   (a) impurities washed out (b) heat is generated (c) heat is absorbed (d) none of the above
10. Cement used in the construction of docks and harbours is
   (a) sulphate resisting Portland cement (b) oil well cement (c) air-entraining cement (d) OPC
11. Which cement is used for lining work of deep tube wells?
   (a) sulphate resisting Portland cement (b) oil well cement (c) air-entraining cement (d) OPC
12. What do you mean by normal consistency? What is their importance?
13. What do you mean by heat of hydration? What is their importance?

II) Descriptive Questions

1. Explain about the structure of hydrated cement.
2. Describe with flow diagrams the dry and wet process of manufacture of cement.
3. Explain about the different physical tests conducted on the ordinary Portland cement?
4. Write the short notes on following
   (i) Plasticizers (ii) super plasticizers (iii) retarders (iv) accelerators (v) pozzolanas
5. Enumerate the different types of cements.
6. Write a short note on mineral admixture and chemical admixtures.
7. Explain the functions of admixtures.
8. What are the ingredients of Portland cement? State the functions and limits of each of them.
9. What are the initial and final setting times of different types of cements? What is their importance?

B. Question testing the ability of students in applying the concepts.

I) Multiple Choice Questions:

1. When water is added to cement
   (a) impurities washed out (b) heat is generated (c) heat is absorbed (d) none of the above
2. In Portland cement the quantity of free magnesia should be
   (a) less than 5% (b) less than 10% (c) less than 15% (d) less than 20%
3. The test conducted by vicat's apparatus is for
   (a) fineness (b) compression strength (c) consistency (d) soundness
4. Basically the apparatus used for the determination of heat of hydration is
   (a) hydrometer (b) calorimeter (c) photo meter (d) hygrometer
5. Heat of hydration of cement is expressed in terms of
   (a) gram (b) Kcal (c) cal/gm (d) cal/ cm
6. Le-chateliers method can be used for cement to determine
   (a) soundness (b) normal consistency (c) specific gravity (d) fineness
7. Auto clave method is used for cement to determine
   (a) residue (b) expansion (c) sieve no (d) sulphur content
8. To produce low heat cements, it is necessary to reduce the compound
   (a) C_3A (b) C_3S (c) C_2S (d) C_4AF
9 . Portland cement is heavier than water by about
   (a) 1.15 times (b) 2.30 times (c) 3.85 times (d) 3.15 times

II) Descriptive Questions:

1. What are Bouge's compounds? Explain in detail how each one of these compounds influences the strength & setting properties of cement.
2. Describe the physical and chemical properties of the different types of cements.
3. Write short notes on the following
   a. Chemical composition of OPC 53 grade cement
   b. Structure of hydrated cement

c. Setting time of cement
d. Fineness of cement

4. Write the short notes on following

(i) Fly ash (ii) silica fume (iii) rice husk ash (iv)blast furnace slag (v) metakaolin

5. Calculate the bogue composition of the cements with the oxide composition given below.

Oxide	**Content percent**		
	Cement A	Cement B	Cement C
SiO_2	22.4	25.0	20.7
CaO	68.2	61.0	64.2
Fe_2O_3	0.3	3.0	5.3
Al_2O_3	4.6	4.0	3.9
SO_3	2.4	2.5	2.0

C GATE/ Competitive oriented bits

1. The standard specific gravity value of ordinary Portland cement is
   (a) 2.5 (b) 1.80 (c) 3.10 (d) 3.15
2. An excess of free lime in Portland cement
   (a) is always desirable (b) causes unsoundness (c) gives sound products (d) none
3. If P is the standard consistency of cement, the amount of water used in conducting the initial setting time test on cement is
   (a) 0.65P (b) 0.85P (c) 0.60P (d) 0.78P
4. Air permeability method is used to determine
   (a) setting time (b) soundness of cement (c) specific surface of cement (d) none of the above

UNIT-II

CONCRETE TECHNOLOGY

Objective: To know different types of aggregates

Syllabus: Classification of aggregate-particle shape & texture-bond strength &other mechanical properties of aggregates-specific gravity, bulk density, porosity ,absorption& moisture content of aggregate- bulking of sand-deleterious substance in aggregate –soundness of aggregate-alkali aggregate reaction- thermal properties –sieve analysis-fineness modulus-grading curves- grading of fine and coarse aggregates-gap graded and well graded aggregates as per IS code-maximum aggregate size.

Learning outcomes:

Students will be able to

(i) Understand the classification of aggregates
(ii) Identify the suitability of different types of aggregates for their use.
(iii) understand the various mechanical properties of aggregates like impact test and crushing test and shape tests also.
(iv) Understand the concept of sieve analysis to find out the fineness modulus of both fine aggregate and coarse aggregate.
(v) Understand the grading curves of both fine aggregate and coarse aggregate.
(vi) Finally understand the maximum size of aggregate used in civil engineering construction point of view.

What is an aggregate?

Aggregates are the important constituents of the concrete which give body to the concrete and also reduce shrinkage. Aggregates occupy 70 to 80 % of total volume of concrete. So, we can say that one should know definitely about the aggregates in depth to study more about concrete.

CLASSIFICATION OF AGGRAGATES:

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

(i) According to geological origin:

The aggregates are usually derived from natural sources & may have been naturally reduced by crushing. The suitability of the locally available aggregates depends upon the geological history of the region. Such an aggregate may further be divided into two categories, namely the natural & artificial aggregates.

(a).Natural aggregate:sand, gravel, crushed rock such as granite, quartzite, basalt, sand stone.

All the natural aggregates materials originated from bed rocks. There are three kinds of rocks namely (i) igneous rocks (ii) sedimentary rocks (iii) metamorphic rocks.

- **Igneous Rocks:** Solidification of molten lava forms igneous rocks.

Example: Quartz, granite, basalt, obsidian, pumice, tuff.

- **Sedimentary Rocks**: Obtained by the deposition of weathered and transported pre-existing rocks.

Example: Sandstone, limestone, shale.

- **Metamorphic Rocks:** Formed at a depth under high heat and pressure by the alterations of either igneous rocks or sedimentary rocks.

Example: Marble, slate, schist.

(b)Artificial aggregate: broken brick, air-cooled slag, sintered fly ash , bloated clay.

(ii).Classification of Aggregates Based on Shape:

Aggregates can be classified in many ways. Classification of aggregates based on shape and size such as coarse and fine aggregates are discussed here,

Aggregates are classified based on so many considerations, but here we are going to discuss about their shape and size classifications in detail.

We know that aggregate is derived from naturally occurring rocks by blasting or crushing etc., so, it is difficult to attain required shape of aggregate. But, the shape of aggregate will affect the workability of concrete. So, we should take care about the shape of aggregate. This care is not only applicable to parent rock but also to the crushing machine used.

Aggregates are classified according to shape into the following types

- Rounded aggregates
- Irregular or partly rounded aggregates
- Angular aggregates
- Flaky aggregates
- Elongated aggregates
- Flaky and elongated aggregates

Rounded aggregate

The rounded aggregates are completely shaped by attrition and available in the form of seashore gravel. Rounded aggregates result the minimum percentage of voids (32 – 33%) hence gives more workability. They require lesser amount of water-cement ratio. They are not considered for high strength concrete because of poor interlocking behavior and weak bond strength.

Irregular aggregates

The irregular or partly rounded aggregates are partly shaped by attrition and these are available in the form of pit sands and gravel. Irregular aggregates may result 35- 37% of voids. These will give lesser workability when compared to rounded aggregates. The bond strength is slightly higher than rounded aggregates but not as required for high strength concrete.

Angular aggregates

The angular aggregates consist well defined edges formed at the intersection of roughly planar surfaces and these are obtained by crushing the rocks. Angular aggregates result maximum percentage of voids (38-45%) hence gives less workability. They give 10-20% more compressive strength due to development of stronger aggregate-mortar bond. So, these are useful in high strength concrete manufacturing.

Flaky aggregates

When the aggregate thickness is small when compared with width and length of that aggregate it is said to be flaky aggregate. Or in the other, when the least dimension of aggregate is less than the 60% of its mean dimension then it is said to be flaky aggregate.

Elongated aggregates

When the length of aggregate is larger than the other two dimensions then it is called elongated aggregate or the length of aggregate is greater than 180% of its mean dimension.

Flaky and elongated aggregates

When the aggregate length is larger than its width and width is larger than its thickness then it is said to be flaky and elongated aggregates. The above 3 types of aggregates are not suitable for concrete mixing. These are generally obtained from the poorly crushed rocks.

(iii).Classification of Aggregates Based on Size:

Aggregates are available in nature in different sizes. The size of aggregate used may be related to the mix proportions, type of work etc. the size distribution of aggregates is called grading of aggregates.

The size and shape of the aggregate particles greatly influence the quantity of cement required in concrete mix and hence ultimately economy of concrete. For the preparation of economical concrete mix on should use largest coarse aggregates feasible for the structure. IS-456 suggests following recommendation to decide the maximum size of coarse aggregate to be used in P.C.C & R.C.C mix.

Maximum size of aggregate should be less than

- One-fourth of the minimum dimension of the concrete member.
- One-fifth of the minimum dimension of the reinforced concrete member.
- The minimum clear spacing between reinforced bars or 5 mm less than the minimum cover between the reinforced bars and form, whichever is smaller for heavily reinforced concrete members such as the ribs of the main bars.

Aggregates are classified into 2 types according to size

- Fine aggregate

- Coarse aggregate

Fine aggregate:

It is the aggregate most of which passes 4.75 mm IS sieve and contains only so much coarser as is permitted by specification. According to source fine aggregate may be described as:

- **Natural Sand**– it is the aggregate resulting from the natural disintegration of rock and which has been deposited by streams or glacial agencies
- **Crushed Stone Sand**– it is the fine aggregate produced by crushing hard stone.
- **Crushed Gravel Sand**– it is the fine aggregate produced by crushing natural gravel.

According to size the fine aggregate may be described as coarse sand, medium sand and fine sand. IS specifications classify the fine aggregate into four types according to its grading as fine aggregate of grading Zone-1 to grading Zone-4. The four grading zones become progressively finer from grading Zone-1 to grading Zone-4. 90% to 100% of the fine aggregate passes 4.75 mm IS sieve and 0 to 15% passes 150 micron IS sieve depending upon its grading zone.

the size range of various fine aggregates given below.

Fine aggregate	**Size variation**
Coarse Sand	2.0mm – 0.5mm
Medium sand	0.5mm – 0.25mm
Fine sand	0.25mm – 0.06mm
Silt	0.06mm – 0.002mm
Clay	<0.002

Coarse aggregate:

It is the aggregate most of which is retained on 4.75 mm IS sieve and contains only so much finer material as is permitted by specification. According to source, coarse aggregate may be described as:

- **Uncrushed Gravel or Stone**– it results from natural disintegration of rock
- **Crushed Gravel or Stone**– it results from crushing of gravel or hard stone.

- **Partially Crushed Gravel or Stone**– it is a product of the blending of the above two aggregate.

According to size coarse aggregate is described as graded aggregate of its nominal size i.e. 40 mm, 20 mm, 16 mm and 12.5 mm etc. for example a graded aggregate of nominal size 20 mm means an aggregate most of which passes 20 mm IS sieve.

A coarse aggregate which has the sizes of particles mainly belonging to a single sieve size is known as single size aggregate. For example 20 mm single size aggregate mean an aggregate most of which passes 20 mm IS sieve and its major portion is retained on 10 mm IS sieve.

. the size range of various coarse aggregates given below.

Coarse aggregate	**Size**
Fine gravel	4mm – 8mm
Medium gravel	8mm – 16mm
Coarse gravel	16mm – 64mm
Cobbles	64mm – 256mm
Boulders	>256mm

(iv). Classification based on unit weight:

Type of aggregate	**Specific gravity**	**Unit weight (KN/m^3)**	**Bulk density(Kg/m^3)**	**Examples**
Normal weight	2.5-2.7	23-26	1520-1680	Sand, gravel, granite, sandstone
Heavy weight	2.8-2.9	25-29	2080	Magnetite, baryte
Light weight	-	12	1120	Dolomite,pumice, cinder, clay

Particle shape and texture:

The physical characteristics such as shape, texture and roughness of aggregates significantly influence the mobility (i.e. 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 & flaky.

- The rounded aggregates are available in the form of river or seashore gravel which are fully waterworn or completely shaped by attrition.
- The rounded aggregates require lesser amount water and cement paste for a given workability
- Where as irregular or partly rounded aggregate(pits sands and gravels)are partly shaped by attrition and have rounded edges.
- The angular aggregates possessing well- defined edges formed at the intersection of roughly planer facesare obtained by crushing of rocks.
- The angular aggregates obtained rocks having thickness smaller than the width and/or length are termed as flaky.

Surface texture: 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 honey-combed. The strength of the bond between aggregate and cement paste depends upon the surface structure. The bond is developed of mechanical anchorage and depends 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 as the former can increase the aggregate-cement bond by 75%, which may increase the compressive and flexural strength of concrete up to 20%. 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 rough surface texture.

The shape and surface texture of fine aggregate governs its voids content and thus affect the water requirements of mix significantly. The use of crushed or manufactured sand with proper shape, surface texture and grading has enabled production of highly workable mix with minimum void content.

Bond Strength: Due to difference between the coefficient of thermal expansion of paste and aggregate and to the shrinkage of cement paste during hardening, concrete is in a state of internal stress even if no external forces are present.it is reported that the stresses are likely to be greatest at the past-aggregate interfaces where micro cracks exist, even in concrete that has never been loaded. Under increasing external load, these cracks spread along the interfaces before extending into the paste or aggregate particles. The strength of bond between aggregate and cement paste thus hasan important influence on the strength of concrete. There is no standard test for bond. The role of particle shape is less well understands; the greater specific surface of angular particles should enable greater adhesive force to be developed, but the angular shape probably causes more severe concentrations of internal stresses.

ENGINEERING PROPERTIES OF AGGREGATES

Aggregates are used in concrete to provide economy in the cost of concrete. Aggregates act as filler only. These do not react with cement and water.

But there are properties or characteristics of aggregate which influence the properties of resulting concrete mix. These are as follow.

1. Size & Shape
2. Surface Texture
3. Specific Gravity
4. Bulk Density
5. Voids
6. Porosity & Absorption
7. Bulking of Sand
8. Fineness Modulus of Aggregate
9. Surface Index of Aggregate
10. Deleterious Material
11. Crushing Value of Aggregate
12. Impact Value of Aggregate
13. Abrasion Value of Aggregate

SURFACE TEXTURE

The development of hard bond strength between aggregate particles and cement paste depends upon the surface texture, surface roughness and surface porosity of the aggregate particles.

If the surface is rough but porous, maximum bond strength develops. In porous surface aggregates, the bond strength increases due to setting of cement paste in the pores.

SPECIFIC GRAVITY (NO UNITS)

The ratio of weight of oven dried aggregates maintained for 24 hours at a temperature of 100 to 110^0C, to the weight of equal volume of water displaced by saturated dry surface aggregate is known as specific gravity of aggregates.

Specific gravities are primarily of two types.

- **Absolute specific gravity:** it is 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.
- **Bulk specific gravity/apparent specific gravity:** if the volume of aggregate includes the voids, the resulting specific gravity is called the bulk specific gravity.

Specific gravity is a mean to decide the suitability of the aggregate. Low specific gravity generally indicates porous, weak and absorptive materials, whereas high specific gravity indicates materials of good quality. Specific gravity of major aggregates falls within the range of 2.5 to 2.8.

Specific gravity values are also used while designing concrete mix.

The specific gravity is determined as described in IS:2386(part-3)-1963. The specific gravity is given by:

Specific gravity = (c)/ (a-b)

Apparent specific gravity = (c)/(c-b)

Water absorption = (a-c)/(c) x100%

Where

a = mass of saturated surface dry aggregate in air,

b = mass of saturated surface dry aggregate in water, and

c= mass of ovendry aggregate in air.

BULK DENSITY:

It is defined as the weight of the aggregate required to fill a container of unit volume. It is generally expressed in kg/litre.

The bulk density of an aggregate depends upon their packing; the particle shape and size, the grading and the moisture content. For coarse aggregate ahigher bulkdensity is an indication of fewer voids to be filled by sand and cement.

VOIDS:

The empty spaces between the aggregate particles are known as voids. The volume of void equals the difference between the gross volume of the aggregate mass and the volume occupied by the particles alone.

The void ratio is calculated as

Void ratio = 1 –(bulk density)/(apparent specific gravity)

If the voids in the concrete are more the strength will be below.

POROSITY & ABSORPTION

The minute holes formed in rocks during solidification of the molten magma, due to air bubbles, are known as pores. Rocks containing pores are called porous rocks.

Water absorption may be defined as the difference between the weight of very dry aggregates and the weight of the saturated aggregates with surface dry conditions.

Depending upon the amount of moisture content in aggregates, it can exist in any of the 4 conditions.

- Very dry aggregate (having no moisture)
- Dry aggregate (contain some moisture in its pores)
- Saturated surface dry aggregate (pores completely filled with moisture but no moisture on surface)
- Moist or wet aggregates (pores are filled with moisture and also having moisture on surface)

Moisture Content:

The surface moisture expressed as a % of the weight of the saturated surface dry aggregate is known as moisture content. High moisture content increases the effective water/ cement ratio to an appreciable extent and may render the concrete weak.

BULKING OF SAND

It can be defined as in increase in the bulk volume of the quantity of sand (i.e. fine aggregate) in a moist condition over the volume of the same quantity of dry or completely saturated sand. The ratio of the volume of moist sand due to the volume of sand when dry, is called bulking factor.

Fine sands bulk more than coarse sand

When water is added to dry and loose sand, a thin film of water is formed around the sand particles. Interlocking of air in between the sand particles and the film of water tends to push the particles apart due to surface tension and thus increase the volume. But in case of fully saturated sand the water films are broken and the volume becomes equal to that of dry sand.

WHAT CAUSES BULKING OF AGGREGATE?

The moisture present in aggregate forms a film around each particle. These films of moisture exert a force, known as **surface tension,** on each particle. Due to this surface tension each particles gets away from each other. Because of this no direct contact is possible among individual particles and this causes bulking of the volume.

Bulking of aggregate is dependent upon two factors,

1. Percentage of moisture content
2. Particle size of fine aggregate

Bulking increases with increase in moisture content upto a certain limit and beyond that the further increase in moisture content results in decrease in volume. When the fine aggregate is completely saturated it does not show any bulking. Fine sand bulks more as compared to coarse sand, i.e. percentage of bulking in indirectly proportional to the size of particle.

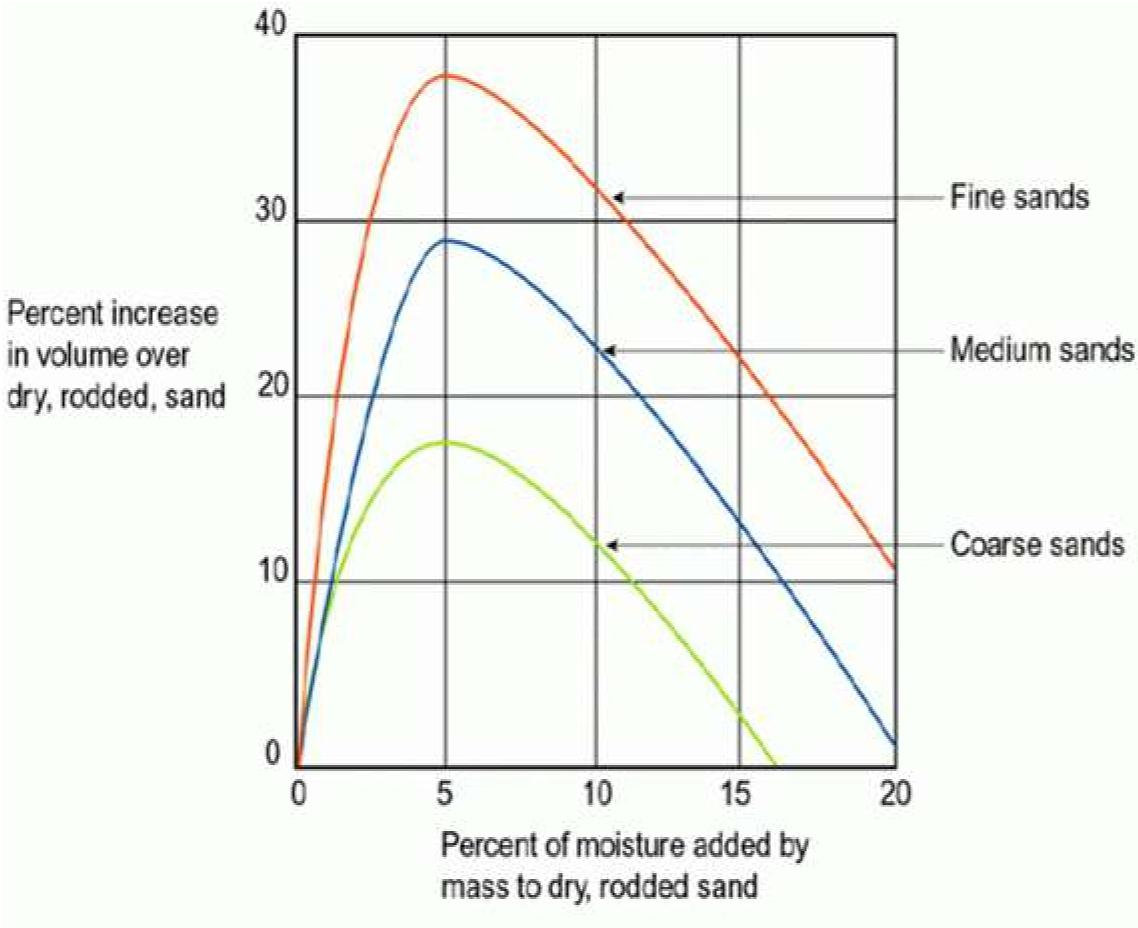


Fig.2Percentage of bulking of sand with moisture content

WHY TO DETERMINE PERCENTAGE OF BULKING?

Due to bulking, fine aggregate shows completely unrealistic volume. Therefore, it is absolutely necessary that consideration must be given to the effect of bulking in proportioning the concrete by volume. It will also affect the yield of concrete for given cement content.

HOW TO DETERMINE PERCENTAGE OF BULKING?

The extent of bulking can be estimated by a simple field test.

- Fill a sample of moist fine aggregate (sand) into a measuring cylinder in the normal manner. Note down the level, say $\mathbf{h_1}$.
- Pour water into a measuring cylinder and completely cover the sand with water and shake it. Since the volume of the saturated sand is the same as that of the dry sand, the saturated sand completely offsets the bulking effect. Note down the level of sand, say $\mathbf{h_2}$.
- Subtract the final level h2 from initial level h1 (i.e. $\mathbf{h_1-h_2}$), which shows the bulking of sand under test.

- Calculate percentage of bulking using formula given below.
- Percentage of bulking = **$[(h_1-h_2)/h_2]*100$**

DELETERIOUS MATERIALS

Aggregates should not contain any harmful material in such a quantity so as to affect the strength and durability of the concrete. Such harmful materials are called deleterious materials. Deleterious materials may cause one of the following effects

- To interfere hydration of cement
- To prevent development of proper bond
- To reduce strength and durability
- To modify setting times

Deleterious materials generally found in aggregates, may be grouped as under

- Organic impurities
- Clay , silt & dust

CRUSHING TEST VALUE ON AGGREGATES:

The aggregates crushing value gives a relative measure of resistance of an aggregate to crushing under gradually applied compressive load. The aggregate crushing strength value is a useful factor to know the behavior of aggregates when subjected to compressive loads.

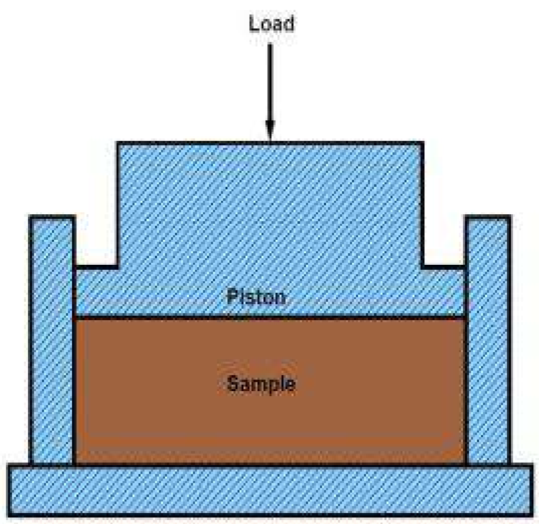


Fig-2.2 Crushing Test Setup

One of the model in which pavement material can fail is by crushing under compressive stress. A test is standardized by **IS: 2386 part-IV** and used to determine the crushing strength of aggregates. The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied crushing load.

The test consists of subjecting the specimen of aggregate in standard mould to a compression test under standard load conditions (See Fig-1). Dry aggregates passing through 12.5 mm sieves and retained 10 mm sieves are filled in a cylindrical measure of 11.5 mm diameter and 18 cm height in three layers. Each layer is tamped 25 times with at standard tamping rod. The test sample is weighed and placed in the test cylinder in three layers each layer being tamped again. The specimen is subjected to a compressive load of 40 tonnes gradually applied at the rate of 4 tonnes per minute. Then crushed aggregates are then sieved through 2.36 mm sieve and weight of passing material (**W2**) is expressed as percentage of the weight of the total sample **(W1**) which is the aggregate crushing value.

Aggregate crushing value = (W1/W2)*100

A value **less than 10** signifies an exceptionally **strong aggregate** while **above 35** would normally be regarded as **weak aggregates**.

Also Read: Crushing Test Procedure of Aggregate

Also read: Crushing Value Test Procedure of Aggregates

Also read: Crushing Value Test of Aggregates

IMPACT TEST VALUE ON AGGREGATES:

The aggregate impact value gives a relative measure of the resistance of an aggregate to sudden shock or impact. The impact value of an aggregate is sometime used as an alternative to its crushing value.

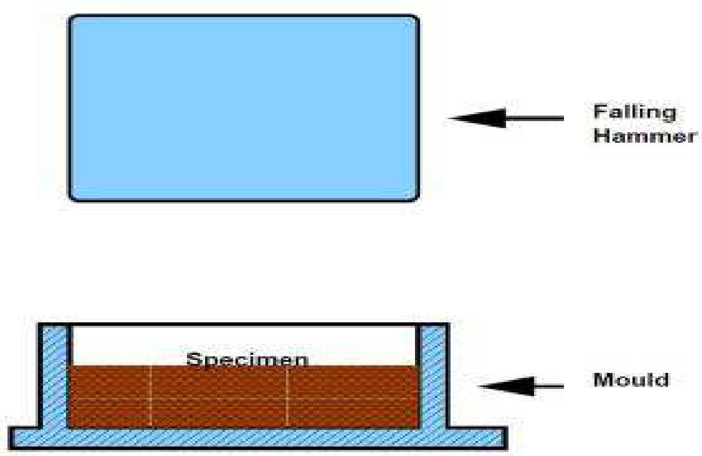


Fig-2.3 Impact Test Setup

The aggregate impact test is carried out to evaluate the resistance to impact of aggregates. Aggregates passing 12.5 mm sieve and retained on 10 mm sieve is filled in a cylindrical steel cup of internal dia 10.2 mm and depth 5 cm which is attached to a metal base of impact testing machine. The material is filled in 3 layers where each layer is tamped for 25 numbers of blows (see Fig-3). Metal hammer of weight 13.5 to 14 Kg is arranged to drop with a free fall of 38.0 cm by vertical guides and the test specimen is subjected to 15 numbers of blows. The crushed aggregate is allowed to pass through 2.36 mm IS sieve. And the impact value is measured as percentage of aggregates passing sieve (**W2**) to the total weight of the sample (**W1**).

Aggregate impact value = (W1/W2)*100

Aggregates to be used **for wearing course**, the impact value **shouldn't exceed 30 percent**. For **bituminous macadam** the **maximum** permissible value is **35 percent**. For **Water bound macadam** base courses the maximum permissible value defined by IRC is **40 percent.**

Also read: Impact Value Test Procedure of Aggregates

Also read: Impact Value Test of Aggregates

ABRASION VALUE OF AGGREGATES:

The abrasion value gives a relative measure of resistance of an aggregate to wear when it is rotated in a cylinder along with some abrasive charge.

Also read: Abrasion Value Test of Aggregates

1. **ABRASION TEST**

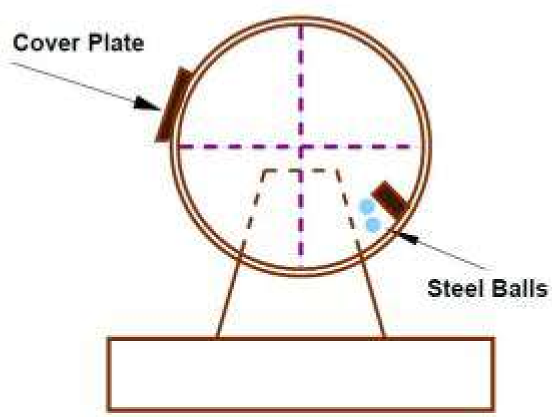


Fig-2.4 Los Angeles Abrasion Test Setup

Abrasion test is carried out to test the hardness property of aggregates and to decide whether they are suitable for different pavement construction works. Los Angeles abrasion test is a preferred one for carrying out the hardness property and has been standardized in India (**IS: 2386 part-IV**).

The principle of Los Angeles abrasion test is to find the percentage wear due to relative rubbing action between the aggregate and steel balls used as abrasive charge.

Los Angeles machine consists of circular drum of internal diameter 700 mm and length 520 mm mounted on horizontal axis enabling it to be rotated (see Fig-2). An abrasive charge consisting of cast iron spherical balls of 48 mm diameters and weight 340-445 g is placed in the cylinder along with the aggregates. The number of the abrasive spheres varies according to the grading of the sample. The quantity of aggregates to be used depends upon the gradation and usually ranges from 5-10 kg. The cylinder is then locked and rotated at the speed of 30-33 rpm for a total of 500

-1000 revolutions depending upon the gradation of aggregates.

After specified revolutions, the material is sieved through 1.7 mm sieve and passed fraction is expressed as percentage total weight of the sample. This value is called Los Angeles abrasion value.

A maximum value of **40 percent** is allowed for **WBM base course** in Indian conditions. For **bituminous concrete**, a maximum value of **35 percent** is specified.

Also read: Los Angeles Abrasion Value Test Procedure of Aggregates

FINENESS MODULUS:

Fineness modulus is an empirical factor obtained by adding the cumulative percentages of aggregate retained on each of the standard sieves ranging from 80 mm to 150 micron and dividing this sum by 100.

Fineness modulus is generally used to get an idea of how coarse or fine the aggregate is. More fineness modulus value indicates that the aggregate is coarser and small value of fineness modulus indicates that the aggregate is finer.

WHAT IS FINENESS MODULUS OF AGGREGATE?

Fineness modulus is an empirical factor obtained by adding the cumulative percentages of aggregate retained on each of the standard sieves ranging from 80 mm to 150 micron and dividing this sum by 100.

WHY TO DETERMINE FINENESS MODULUS?

- Fineness modulus is generally used to get an idea of how coarse or fine the aggregate is. More fineness modulus value indicates that the aggregate is coarser and small value of fineness modulus indicates that the aggregate is finer.
- Fineness modulus of different type of sand is as per given below.

Type of Sand	Fineness Modulus Range
Fine Sand	2.2 – 2.6
Medium Sand	2.6 – 2.9
Coarse Sand	2.9 – 3.2

Generally sand having fineness modulus more than 3.2 is not used for making good concrete.Fineness modulus can also be used to combine two aggregate to get the desirable grading.

HOW TO DETERMINE FINENESS MODULUS?

Following procedure is adopted to calculate fineness modulus of aggregate.

PROCEDURE

- Sieve the aggregate using the appropriate sieves (80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 micron, 300 micron & 150 micron)
- Record the weight of aggregate retained on each sieve.
- Calculate the cumulative weight of aggregate retained on each sieve.
- Calculate the cumulative percentage of aggregate retained.
- Add the cumulative weight of aggregate retained and divide the sum by 100. This value is termed as fineness modulus
- Refer the following example calculation

Example Calculation of Fineness Modulus of Fine Aggregate (by sieve analysis)

Sieve Size	**Weight of sand Retained (gm)**	**Cumulative weight of sand retained (gm)**	**Cumulative percentage of sand retained (%)**	**Cumulative % passing**
80 mm	–	–	–	-
40 mm	–	–	–	-
20 mm	–	–	–	-
10 mm	0	0	0	100
4.75 mm	10	10	2	98
2.36 mm	50	60	12	88
1.18 mm	50	110	22	78
600 micron	95	205	41	59

300 micron	175	380	76	24
150 micron	85	465	93	7
Pan	35	500		-
Total amount =	500		Total = 246	

So **Fineness Modulus = 246/100 = 2.46**

SOUNDNESS OF AGGREGATE:

The soundness of aggregate as the ability of aggregate to resist changes in volume as aresult of changes in physical conditions. The conditions affecting this property are freezing and thawing temperature changes, and alternate wetting and drying, porous and weak aggregate containingundesirable extraneous matter undergo excessive volume changes under favourable conditions,the freeze- thaw resistance of aggregate is related to its porosity, absorption and pore structure. This may cause local scaling to surface cracking consequently leading to impaired appearance and sometimes structural failure. Aggregate may also be chemically unstable. Some of the aggregate with certain chemical constituents react with alkalis in cement which may cause abnormal expansion and may cracking of concrete.

ALKALI AGGREGATE REACTION:

The alkali aggregate reaction (AAR) or alkali-silica reactivity (ASR) is the reaction between active silica constituents of the aggregate and alkalies, i.e. Na_2O and K_2O present in the cement. The reactive forms of silica generally occur in the aggregates obtained from traps, andisites, rhyolites, siliceous lime stone and certain types of sand stones. The reactive components may be in the forms of opals, cherts, chalcedony, volcanic glass, zeolites and tridmite. The expansive alkali-silicate gels are formed due to the reactionwhen conditions are congenial and progressive manifestation by swelling takes place which result in disruption of concrete with the spreading of pattern cracks and eventual failure of concrete structures. However, only such aggregates which contain reactive silica in particular proportions and in particular fineness are found to exhibit tendencies for alkali-aggregate reaction. High alkali content in cement; availability of moisture and optimum temperature conditions.

Alkali –aggregate reaction mechanism: The soluble alkalies in the cement dissolve in the mixing water turning it into a highly caustic liquid which reacts with the reactive silica present in the reactive aggregates to form highly expansive alkali-silica gel altering the boundries of aggregate. The expansive growth due to continuous supply of water and correct temperature results from unabated formation of silica gel. As the silica gel is confined by the surrounding paste the continuous growth of silica gel exerts internal hydraulic pressure generated through osmosis on the surrounding set- cement gel to cause pattern cracking with subsequent loss in strength and elasticity particularly in thinner sections like pavements. The formation of cracks due to alkali-aggregate reaction accelerates other processes of deterioration like carbonation.

Factors promoting and controlling AAR:

1. Reactive type of aggregates
2. High alkali content in cement
3. Availability of moisture
4. Optimum temperature conditions

Control of alkali aggregate reaction:

1. Selection of non reactive aggregates
2. by the use of low alkali cement
3. by the use of corrective admixtures such as pozolanas
4. By controlling the void spacing concrete
5. by controlling moisture condition and temperature

THERMAL PROPERTIES OF AGGREGATES:

The thermal properties of the aggregates affect the durability and the other qualities of concrete. The investigations reported to date do not present a clear- cut picture of the effects that effects that might be expected.

The principal thermal properties of the aggregate are (i) coefficient of thermal expansion (ii) specific heat (iii) thermal conductivity.

The coefficient of thermal expansion of the concrete increases with the coefficients of thermal expansion of aggregate. If the coefficient of expansion of coarse aggregate and of cement paste differs too much, a large change in temperature may introduce differential movement which may break the bond between the aggregate and the aggregate and the paste. If the coefficients of the two materials differ by more than 5.4×10^{-6} per ^{0}C, the durability of concrete subjected to freezing and thawing may be affected.

The coefficient of expansion of the aggregate depends upon parent rock. For majority of aggregates, the coefficient of thermal expansion lies between approximately $5.4\text{x}10^{-6}$ per ^{0}C and $12.6\ \text{x}10^{-6}$ per ^{0}C. For hydrated Portland cement the coefficients varies between $10.8\text{x}10^{-6}$ per ^{0}C and $16.2\text{x}10^{-6}$ per ^{0}C.

Whereas, the linear thermal coefficients of expansion of concrete lies in the range of about $5.8\text{x}10^{-6}$ per ^{0}C to $14\text{x}10^{-6}$ per ^{0}C depending upon the type of aggregate, mix proportions, degree of saturation.

The specific heat of the aggregate is measure of its heat capacity, whereas the thermal conductivity is the ability of the aggregate to conduct the heat. These properties of the aggregate influence the specific heat and thermal conductivity of the concrete, and are important in the case of mass concrete and insulation is required.

Maximum size of the aggregate:

For the same strength or workability, concrete with large size aggregate will require lesser quantity of cement than concrete with a smaller size aggregate. In a mass concrete work the use of larger size aggregate will be useful due to the lesser consumption of cement. This will also reduce the heat of hydration and the corresponding thermal stresses and shrinkage cracks. But in practice the size of aggregate cannot be increased to any limit on account of the limitation in the mixing, handling and placing equipment. In large size aggregates surface area to be wetted per unit weight is less, and the water cement ratio is less which increases the strength. On the other hand in smaller size aggregates the surface area is increased which increases w/c ratio and lower strength is achieved. In general for strength up to 200 kg/cm^2 aggregates up to 40 mm may be used and for strength above 300 kg/cm^2 aggregate up to 20 mm may be used.

CONDITIONS THAT DECIDE MAXIMUM SIZE OF COARSE AGGREGATE TO BE USED IN CONCRETE

The following conditions decide the maximum size of coarse aggregate to be used in concrete

1. It should not be more than one fourth of the minimum thickness of the member provided that the concrete can be placed without difficulty so as to around all reinforcement thoroughly and fill the corner of the form.
2. Plump (large undressed stone embedded with others in concrete on large work) above 160 mm and upto any reasonable size may be used in plain concrete work up to a maximum limit of 20 percent by volume of concrete.
3. For heavily reinforced concrete members the nominal maximum size of the aggregate should be usually restricted to 6 mm less than the minimum clear distance between the main bar or 5 mm less than the minimum cover to the reinforcement, whichever is less.
4. Where the reinforcement is widely spaced as in solid slabs, limitations of the size of the aggregate may not be so important and the nominal maximum size may sometime be as great as or greater than the maximum cover except where porous aggregate are used.
5. For reinforced concrete work aggregates having a maximum size of 20 mm are generally considered satisfactory.

GRADING LIMITS FOR FINE AGGREGATES IS:383-1970

Sieve Size	Percentage of Passing For			
	Grading Zone-I	Grading Zone-II	Grading Zone-III	Grading Zone-IV
10 mm	100	100	100	100

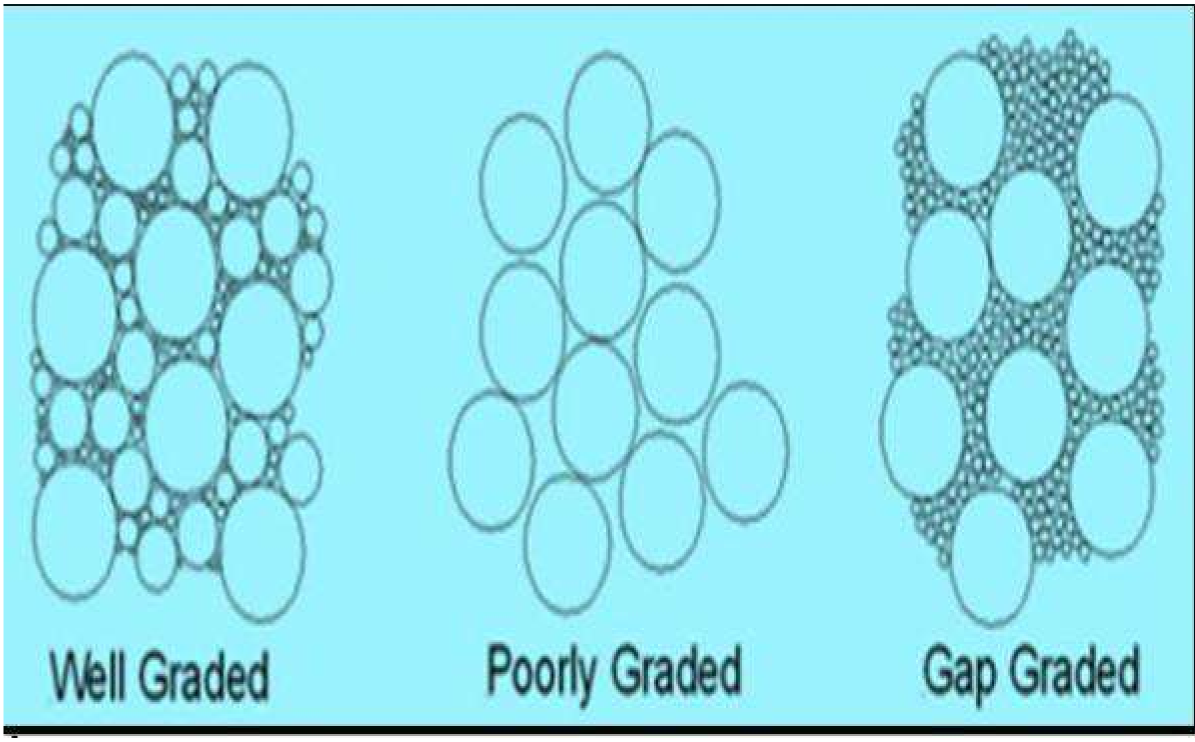
4.75 mm	90 – 100	90 – 100	90 – 100	95 – 100
2.36 mm	60 – 95	75 – 100	85 – 100	95 – 100
1.18 mm	30 – 70	55 – 90	75 – 100	90 – 100
600 micron	15 – 34	35 – 59	60 – 79	80 – 100
300 micron	5 – 20	8 – 30	12 – 40	15 – 50
150 micron	0 – 10	0 – 10	0 – 10	0 – 15

IMPORTANT NOTES

- Since the values for 600 micron size are not overlapping for different zones, it is used for confirming the zone of a sample of fine aggregate.
- Zone-I represents the coarse sand and zone-IV represents the finer sand in all the four zones.
- Fine aggregate belonging to zone-IV should not be used in RCC work unless tests have been made for suitability of mix proportion.

WHAT IS GAP GRADED AGGREGATE?

Generally we use well graded aggregate or continuous graded aggregate, which means representation of all the standard particle sizes in certain proportion. Assumption made in well gradation is that voids created by the higher size of aggregate will be filled-up by immediate next lower size of aggregate and again some smaller voids will be left out which will again be filled-up by next lower size aggregates.



Fig

Fig.2.5 Aggregate gradation

Practically it has been found that voids created by a particular size may be too small to accommodate the very next lower size. Therefore the next lower size may not be accommodated in the available gap without lifting the upper layer of the existing size. Therefore, **Particle Size Interference** is created which disturbs the very process of achieving the maximum density.

In fact the size of voids created by a particular size of aggregate can accommodate the second or third lower size aggregates only i.e. voids created by 40 mm will be able to accommodate size equal to 10 mm or 4.75 mm but not 20 mm. This concept is called **Gap Grading**.

ADVANTAGESOF GAP GRADING

1. Requirements of sand are reduced by 26 to 40%.
2. Specific area of area of total aggregates will be reduced due to less use of sand..
3. Point contact between various size fractions is maintained, thus reducing the dying shrinkage.
4. It requires less cement as the net volume of voids to a greater extent.

NOTE

A word of caution while using gap grading is that, sometimes it may lead to segregation and may even alter the anticipated workability. Therefore tests must be conducted before adopting this gradation.

Importance of aggregate grading in concrete:

Concrete is prepared by mixing aggregate, cement and water in such a proportion that it becomes **workable** in its plastic state and **durable** in its hardened state.

Our aim is to satisfy both of these requirements i.e. workability and durability.

A workable concrete can be achieved by adding more water, but as we know the more water present in concrete the poor strength it gives. The most efficient way to achieve workable of concrete is by adopting a good gradation of aggregate.

Also aggregate comprises 85% of the volume of concrete. So we can definitely say that, most of the requirement of concrete in its plastic state is affected by aggregate properties and, "**gradation of aggregate"** is one of them.

We use cement paste to bind all the aggregates (i.e. fine and coarse) so as to give a compact mass, and this is why concrete is considered as a two phase material, namely, paste phase and aggregate phase.

The paste has following disadvantages as compared to aggregate and, which affects the concrete in its durability aspect.

- Paste is more permeable than aggregate
- Paste has less strength than aggregate
- Paste is more susceptible to chemical attack as compared to aggregate.

The only way to minimize above factors is to use less amount of cement paste to produce concrete. This is achieved if we use a good gradation of aggregate which gives minimum voids. A sample containing minimum voids will require minimum paste to fill up the voids in the aggregates. Minimum paste will mean less quantity of cement and less quantity of water, which will further means increased economy, higher strength, lower shrinkage and greater durability.

Standard grading curve:

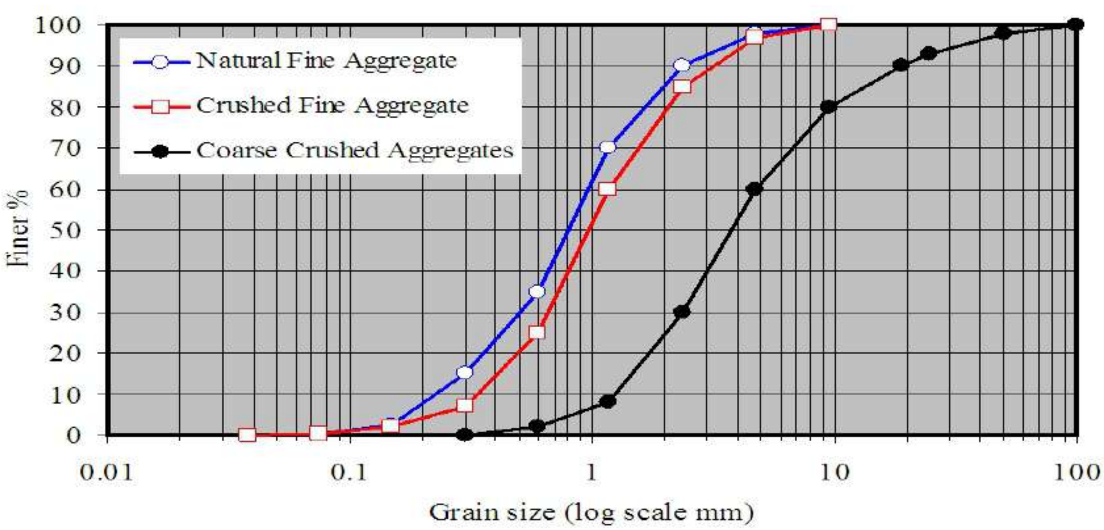


Fig 2.6 Grading curve

Assignment-Cum-Tutorial Questions

A. Questions testing the remembering / understanding level of students

I) Objective Questions

1. Aggregate can be classified according to

   (a)geological origin (b) size (c) shape (d) unit weight (e) all of the above

2. Which of the following aggregates gives maximum strength in concrete?

   (a) Rounded (b) elongated (c) flaky (d) cubical

3. The best reflection of strength of coarse aggregate is given by

   (a) Crushing (b) impact (c) 10% fines (d) hardness

4. For high strength concrete the best aggregate

   (a) Rounded (b) irregular (c) angular (d) all-in aggregate

5. The maximum bulking of sand is likely to occur at a moisture content of

   (a) 5% (b) 8% (c) 10% (d) 15%

6. The bulk density of aggregates is expressed as

   (a) kg/cubic metre (b) tonnes/ cubic metre (c) kg/lit (d) gm/ lit

7. If the fineness modulus of sand is 2.5 it is graded as

   (a) very coarse sand (b) coarse sand (c)medium sand (d) fine sand (e) very fine sand

8. What is meant by fine aggregate?

9. What is meant by coarse aggregate?

10. What is bulking of sand?

11. What is alkali aggregate reaction?

12. What is meant by soundness of aggregate?

13. What is a gap-graded mix?

14. Define toughness of aggregate?

15. What are the advantages of a gap-graded mix?

II) Descriptive Questions

1. How are the aggregates classified, explain?
2. Explain the mechanical properties of aggregates (impact, crushing& abrasions tests & shape tests).
3. Write a short notes on the following items
   (a) Bulk Specific gravity (b) bulk density (c) porosity (d) absolute specific gravity
4. Explain the properties of (i) light weight aggregate (ii) normal weight aggregate (iii) heavy aggregate.
5. What is the effect of particle shape and texture on the strength of the aggregate?

B. Questions testing the ability of students in applying the concepts.

I) Multiple Choice Questions:

1. Bulking of sand is due to

(a)viscosity

(b)air voids

(c) surface moisture

2. If the fineness modulus of fine aggregate is 2.51, it can be graded as

(a)fine sand

(b)medium sand

(c)very fine sand

(d)coarse sand

3.Concrete with aggregate of higher modulus of elasticity will shrink

(a)by same amount

(b)less

(c)more

(d)more or less the same

4.Increase in the fineness modulus of aggregates indicates

(a)gap grading

(b)finer grading

(c)coarser grading

(d)both a and c

5.Grading of aggregate in a concrete mix is necessary to achieve

(a)Adequate workability

(b)Higher density

(c) reduction of voids

(d)Better durability

6. Bulking of sand is maximum if the percentage of moisture content is of the order of

(a)5

(b)8

(c) 10

(d)15

7. Aggregates for use in concrete should be in

(a)Wet condition

(b)Surface dry condition

(c) Moist surface condition

(d)All of the above

8. What is meant by fineness modulus of aggregate?

9. Define the (i) elongation index (ii) flakiness index of aggregates

10. What is meant by alkali-aggregate reaction?

II) Descriptive Questions:

1. Write a short note on bulking of sand.
2. Write about gap graded and well graded aggregate.
3. Write about bulk density and moisture absorption of aggregates?
4. What is fineness modulus? How would you find the fineness modulus value of coarse and fine aggregate?
5. What are the deleterious substances in aggregates? What are their harmful effects?
6. Write about the thermal properties of aggregates.
7. Write about grading of curves and fineness modulus of aggregates.
8. Write short notes on soundness of aggregate and AAR.

9. Explain the following items:
   (a) Gap graded aggregate (b) well graded aggregate (c) maximum size of aggregate

C. Questions testing the analyzing /evaluating ability of students

1. Analyze the properties of aggregate from different sources of origins?

2. Discuss the suitability of sea water in to use in concrete.

3. Discuss on strength of concrete and maximum size of aggregate.

D. GATE/ Competitive oriented bits

1. The presence of common salt in sand results in

(a)Corrosion of reinforcement

(b)Scaling

(c)Pitting

(d)All the above

2. With the increase in the angularity no of aggregates, the workability of concrete will

(a)Increase

(b)Not change

(c)Decrease

(D)None of the above

3. In concrete mix design, allowance for bulking of sand is necessary in case of

(a)Weigh batching

(b)Volume batching

(c)Both a&b

(d)None of the above

4. Aggregate used in concrete because

(a)It is a relatively inert material and cheaper than cement

(b)It imparts volume stability and durability to the concrete

(c)It provides bulk to the sand

(d)It increase the density of the concrete mix (e)All the above

5.An aggregate should

(a)Be of proper shape and size

(b)Be clean ,hard and well graded

(c)Possess chemical stability

(d)Exhibit abrasion resistance

(e)All the above

6.An aggregate generally not preferred for use in concrete is one which has the following Surface texture

(a)Smooth

(b)Rough

(c)Glassy

(d)Granular

(e)Honeycombed

7. The cyclopan aggregate has a size more than

(a)4.75mm

(b)20mm

(c)40mm

(d)60mm

(e)75mm

8. Grading of the aggregate

(a)Affects the workability

(b)Affects the strength of concrete

(c)Is dependent on the shape and texture of the particles of the aggregate

(d)Affects the water –cement ratio

(e)All of the above is true.

UNIT – III

Concrete Technology

Objective: To know different types of concretes and their workability

Syllabus: Fresh Concrete & Special Concretes Fresh Concrete: Workability – Factors affecting workability – Measurement of workability by different tests – Setting times of concrete – Effect of time and temperature on workability – Segregation & bleeding, Steps in manufacture of concrete – Quality of mixing water, Tolerable concentrations of some impurities in mixing water, permissible limit for solids as per IS456-2000, use of sea water for mixing concrete. Ready mixed concrete-Introduction, Advantages and Disadvantages

Special Concretes: Light weight aggregates – Light weight aggregate concrete – Cellular concrete – No-fines concrete– High density concrete – Fibre reinforced concrete – Different types of fibres – Factors affecting properties of F.R.C, Polymer concrete – Types of Polymer concrete – Properties of polymer concrete, High performance concrete – Self consolidating concrete, Ferrocement: Casting techniques guniting, applications.

Learning outcomes:

Students will be able to

(i) Understand the properties of ingredients of concrete
(ii) Understand the setting times of concrete
(iii) Understand about the properties of fresh concrete and special concretes
(iv) Understand the impurities in water

Definition of Workability

The property of fresh concrete which is indicated by the amount of useful internal work required to fully compact the concrete without bleeding or segregation in the finished product.

Factors affecting workability:

- Cement content of concrete
- Water content of concrete
- Mix proportions of concrete
- Size of aggregates
- Shape of aggregates
- Grading of aggregates
- Surface texture of aggregates
- Use of admixtures in concrete

- Use of supplementary cementitious materials

The primary materials of concrete are cement, fine aggregates (sand), coarse aggregates and water. Many times admixtures are used in concrete to enhance its properties. Therefore, properties of these materials and their content affect the workability of concrete. Following are the general factors affecting concrete workability

Cement Content of Concrete:

Cement content affects the workability of concrete in good measure. More the quantity of cement, the more will be the paste available to coat the surface of aggregates and fill the voids between them. This will help to reduce the friction between aggregates and smooth movement of aggregates during mixing, transporting, placing and compacting of concrete. Also, for a given water-cement ratio, the increase in the cement content will also increase the water content per unit volume of concrete increasing the workability of concrete. Thus increase in cement content of concrete also increases the workability of concrete.

Type and Composition of Cement:

There are also effect of type of cement or characteristics of cement on the workability of concrete. The cement with increase in fineness will require more water for same workability than the comparatively less fine cement. The water demand increased for cement with high Al2O3 or C2S contents.

Water / Cement Ratio or Water Content of Concrete:

Water/cement ratio is one of the most important factor which influence the concrete workability. Generally, a water cement ratio of 0.45 to 0.6 is used for good workable concrete without the use of any admixture. Higher the water/cement ratio, higher will be the water content per volume of concrete and concrete will be more workable.

Higher water/cement ratio is generally used for manual concrete mixing to make the mixing process easier. For machine mixing, the water/cement ratio can be reduced. These generalised method of using water content per volume of concrete is used only for nominal mixes. For designed mix concrete, the strength and durability of concrete is of utmost importance and hence water cement ratio is mentioned with the design. Generally designed concrete uses low water/cement ratio so that desired strength and durability of concrete can be achieved.

Mix Proportions of Concrete:

Mix proportion of concrete tells us the ratio of fine aggregates and coarse aggregates w.r.t. cement quantity. This can also be called as the aggregate cement ratio of concrete. The more cement is used, concrete becomes richer and aggregates will have proper lubrications for easy mobility or flow of aggregates. The low quantity of cement w.r.t. aggregates will make the less paste available for aggregates and mobility of aggregates is restrained.

Size of Aggregates:

Surface area of aggregates depends on the size of aggregates. For a unit volume of aggregates with large size, the surface area is less compared to same volume of aggregates with small sizes. When the surface area increases, the requirement of cement quantity also increase to cover up the entire surface of aggregates with paste. This will make more use of water to lubricate each aggregates. Hence, lower sizes of aggregates with same water content are less workable than the large size aggregates.

Shape of Aggregates:

The shape of aggregates affects the workability of concrete. It is easy to understand that rounded aggregates will be easy to mix than elongated, angular and flaky aggregates due to less frictional resistance. Other than that, the round aggregates also have less surface area compared to elongated or irregular shaped aggregates. This will make less requirement of water for same workability of concrete. This is why river sands are commonly preferred for concrete as they are rounded in shape.

Grading of Aggregates:

Grading of aggregates have the maximum effect on the workability of concrete. A well graded aggregates have all sizes in required percentages. This helps in reducing the voids in a given volume of aggregates. The less volume of voids makes the cement paste available for aggregate surfaces to provide better lubricating to the aggregates.

With less volume of voids, the aggregate particles slide past each other and less compacting effort is required for proper consolidation of aggregates. Thus low water cement ratio is sufficient for properly graded aggregates.

Surface Texture of Aggregates:

Surface texture such as rough surface and smooth surface of aggregates affects the workability of concrete in the same way as the shape of aggregates. With rough texture of aggregates, the surface area is more than the aggregates of same volume with smooth texture. Thus concrete with smooth surfaces are more workable than with rough textured aggregates.

Use of Admixtures in Concrete:

There are many types of admixtures used in concrete for enhancing its properties. There are some workability enhancer admixtures such as plasticizers and super plasticizers which increases the workability of concrete even with low water/cement ratio. They are also called as water reducing concrete admixtures. They reduce the quantity of water required for same value of slump.

Air entraining concrete admixtures are used in concrete to increase its workability. This admixture reduces the friction between aggregates by the use of small air bubbles which acts as the ball bearings between the aggregate particles.

Use of Supplementary Cementitious Materials:

Supplementary cementitious materials are those which are used with cement to modify the properties of fresh concrete. Fly ash, fibers, silica fume, slag cements are used as supplementary cementitious materials.

The **use of fly ash** in improves the workability of concrete by reducing the water content required for same degree of workability or slump value.

The **use of steel or synthetic fibers in concrete** reduces the workability of concrete as it makes the movement of aggregates harder by reducing the lubricating effect of cement paste.

The workability of concrete is reduced and increased based on the quantity of **silica fume**. The use of silica fume in concrete can improves workability when used at low replacement rates, but can reduce workability when added at higher replacement rates. Silica fume are used as pumping aid for concrete when used as 2 to 3% by mass of cement.

The **use of slag cement** also improves workability but its effect depends on the characteristics of the concrete mixture in which it is used.

Different Test Methods for Workability Measurement

Depending upon the water cement ratio in the concrete mix, the workability may be determined by the following three methods.

1. Slump Test
2. Compaction Factor Test
3. Vee-bee Consistometer Test

1. Slump Test

This method is suitable only for the concrete of high workability.

This test is carried out with a mould called slump cone whose top diameter is 10 cm, bottom diameter is 20 cm and height is 30 cm.

Fig 3.1 Slump test apparatus

Procedure

The test is performed in the following steps:

1. Place the slump mould on a smooth flat and non-absorbent surface.
2. Mix the dry ingredients of the concrete thoroughly till a uniform colour is obtained and then add the required quantity of water in it.
3. Place the mixed concrete in the mould to about one-fourth of its height.
4. Compact the concrete 25 times with the help of a tamping rod uniformly all over the area.
5. Place the mixed concrete in the mould to about half of its height and compact it again.
6. Similarly, place the concrete upto its three-fourth height and then up to its top. Compact each layer 25 times with the help of tamping rod uniformly. For the second and subsequent layers, the tamping rod should penetrate into underlying layer.
7. Strike off the top surface of mould with a trowel or tamping rod so that the mould is filled to its top.
8. Remove the mould immediately, ensuring its movement in vertical direction.
9. When the settlement of concrete stops, measure the subsidence of the concrete in millimeters which is the required *slump* of the concrete.

Recommended Slump Values for Various Concrete Works

Type of Construction	**Recommend slump in mm**	
	Minimum	**Maximum**

Pavements	25	50
Mass concrete structure	25	50
Unreinforced footings	25	75
Caissons and bridge decks	25	75
Reinforced foundation, footings and walls	50	100
Reinforced slabs and beams	30	125
Columns	75	125

Limitations of Slump Test

Following are the limitations

- Not suitable for concrete containing aggregates larger than 40 mm.
- Not suitable for concrete of dry mix.
- Not suitable for very wet concrete.
- Not reliable because slump may be of any shape.

2. Compaction Factor Test

According to this test, the workability may be defined as the amount of applied work required to compact the concrete to its maximum density.

This method is adopted for determining the workability of concrete mix in laboratories. It gives fairly good results for concrete of low workability.

Procedure

The apparatus required for performing the compaction factor test is shown below.

Fig 3.2.Compaction factor apparatus

1. The test is performed in the following steps:
2. Clean and dry the internal surface of the mould.
3. With the help of hand scoop, place the concrete in upper hopper A.
4. Open the trap door of hopper in order to facilitate the falling of the concrete into lower hopper B. the concrete sticking to the sides of the hopper A, should be pushed downward with the help of a steel rod.
5. Open the trap door of the hopper B and allow the concrete to fall into cylinder C.
6. Remove the surplus concrete from the top of the cylinder with the help of a trowel. Wipe and clean the outside surface of the cylinder.
7. Weigh the cylinder with partially compacted concrete nearest to 10 g.
8. Fill in the cylinder with fresh concrete in layers not exceeding 5 cm in thickness and compact each layer till 100 percent compaction is achieved.
9. Wipe off and clean the outside surface of the cylinder and weigh the cylinder with fully compacted concrete nearest to 10 g.
10. Calculate the value of compaction factor using the following formula.

Compaction factor = weight of partially compacted concrete/weight of fully compacted concrete

Recommended Values of Workability for Various Placing Conditions

Conditions	**Degree**	**Values of Workability**
Concreting of shallow sections with vibrations	Very low	20 – 10 seconds Vee-Bee time or 0.75 to 0.80 compacting factor
Concreting of lightly reinforced sections with vibrations	Low	10 – 5 seconds Vee-Bee time or 0.80 to 0.85 compacting factor
Concreting of lightly reinforced sections without vibrations or heavily reinforced sections with vibrations	Medium	5-2 seconds Vee-Bee time or 0.85 to 0.92 compacting factor or 25 – 75 mm slumps for 20 mm aggregates
Concreting of heavily reinforced sections without vibrations	High	Above 0.92 compacting factor or 75 – 125 mm slump for 20 mm aggregates.

Advantages of Compaction Factor Test

Following are the advantages:

- Suitable for testing workability in laboratories
- Suitable for concrete of low workability
- Suitable to detect the variation in workability over a wide range
- Its results are more precise and sensitive.

3. Vee-bee Consistometer Test

The apparatus used in this method of test is shown below.

Fig 3.3.V-bee consistometer

This method is suitable for dry concrete having very low workability

Procedure

The test is performed as given described below

1. Mix the dry ingredients of the concrete thoroughly till a uniform colour is obtained and then add the required quantity of water.
2. Pour the concrete into the slump cone with the help of the funnel fitted to the stand.
3. Remove the slump mould and rotate the stand so that transparent disc touches the top of the concrete.
4. Start the vibrator on which cylindrical container is placed.
5. Due to vibrating action, the concrete starts remoulding and occupying the cylindrical container. Continue vibrating the cylinder till concrete surface becomes horizontal.
6. The time required for complete remoulding in seconds is the required measure of the workability and it is expressed as number of Vee-bee seconds.

COMPARISON OF WORKABILITY MEASUREMENTS BY VARIOUS METHODS

Workability Description	**Slump in mm**	**Vee-bee Time in Seconds**	**Compacting Factor**
Extremely dry	–	32 – 18	
Very stiff	–	18 – 10	0.70

Stiff	0 – 25	10 – 5	0.75
Stiff plastic	25 – 50	5 – 3	0.85
Plastic	75 – 100	3 – 0	0.90
Flowing	150 – 175	–	0.95

SETTING TIME OF CONCRETE:

Setting time of concrete differs widely from setting time of cement. Setting time of concrete does not coincide with the setting time of cement with which the concrete is made. The setting time of concrete depends upon the W/C ratio, temperature conditions, type of cement, use of mineral admixtures, use of plasticizers – particular retarding plasticizers. When the retarding plasticizers are used, increasing setting time, the duration up to which concrete remains in plastic condition is of special interest.

The setting time of concrete is found by penetrometer test.(IS:8142-1976)

PROCEDURE

The apparatus consists of a container which should have minimum lateral dimension of 150mm and minimum depth of 150mm. There are six penetration needles with bearing areas of 16,32,65,161,323 and 645mm^2 . each needle is stem is scribed circumferentially at a distance of 25mm from the bearing area.

Fig3.4: Needle with different bearing area

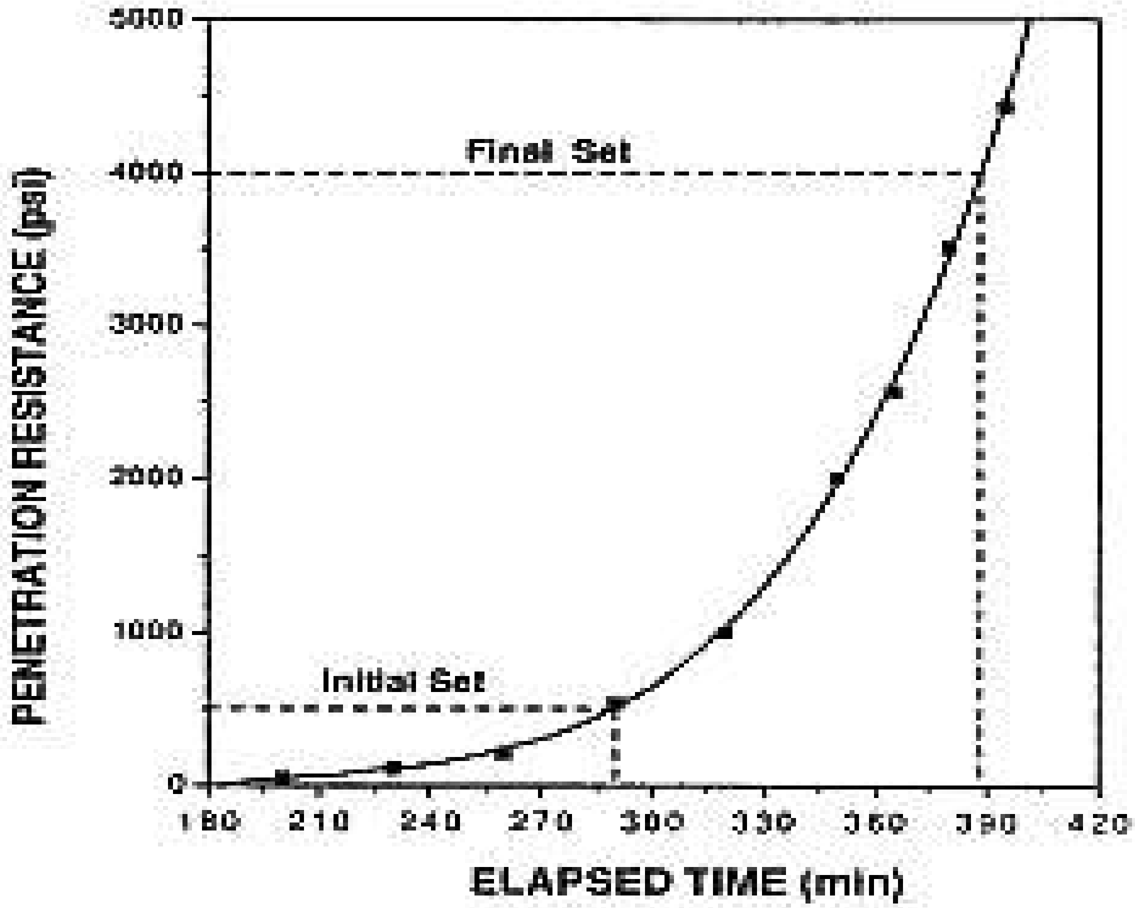


FIG. X1.1 Plot of Penetration Resistance Versus Elapsed Time and Hand Fit Curve Used to Determine Times of Setting

A device is provided to measure the force required to cause penetration of the needle. The test procedure involves the

- Collection of representative sample of concrete insufficient quantity and sieve it through 4.75mm sieve and the resulting mortar is filled in the container.
- Compacting the mortar by rodding , tamping or by vibrating.
- Level the surface and keep it covered to prevent the loss of moisture.
- Remove bleeding water, if any , by means of pipette.
- Insert a needle of appropriate size, depending upon the degree of setting of the mortar in following manner.
- Bring the bearing surface of the needle in contact with the mortar surface.
- Gradually and uniformly apply a vertical force downwards on the apparatus until the needle penetrates to a depth of 25±1.5mm, as it indicated by the scribe mark.
- The time taken to penetrate 25mm depth could be about 10 secs.
- Record the force required to produce 25mm penetrations and the time of inserting from the time water is added to cement.
- Calculate the penetration resistance by dividing the recorded force by the bearing area of the needle. This is the penetration resistance.
- The clear distance should be two times the diameter of the bearing area. Needle is inserted at least 25mm away from the wall of container.

- From the graph penetration resistance has ordinate and elapsed time is abscissa.

Temperature Effect On Concrete Workability

When fresh concrete is laid at the site then proper curing of concrete is required, because structures are exposed to the environment and in these conditions if there is no such an arrangement against the environment, then there are many factors that affect the workability of concrete and temperature is One of them. Temperature, almost in every aspect has negative effects on the properties of concrete and same is the case with the workability of fresh concrete.

When temperature increases, then in the same proportion workability of fresh concrete decreases. The reason that stands behind is " when temperature increases then evaporation rate also increases due to that hydration rate decreases and hence, concrete will gain strength earlier ". Due to fast hydration of concrete, a hardening comes in concrete and that decreases the workability of fresh concrete. Therefore, In return manipulation of concrete become very difficult.

Time Effect On Concrete Workability

Effect of 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 wing, 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 loss about 50 mm slump in the first one hour. The workability in terms of compacting factor decreases by about 0.10 during the period of one 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 workability is small and initial level could be regained without loss in the strength of hardened concrete simply by adding extra water.

Bleeding and segregation

Bleeding is a form of segregation where some of the water in the concrete tends to rise to the surface of the freshly placed material. This arises due to the inability of the solid components of the concrete to hold all of the mixing water when they settle downwards (water being the lightest of all the mix constituents). Bleeding of the water continues until the cement paste has stiffened enough to end the sedimentation process.

Cement types can influence bleeding capacity, increased proportions of, for example, cement combinations containing ground granulated blast furnace slag (ggbs), leading to an increase in the time for bleeding continue due to a longer setting time. The presence of an adequate proportion of very fine aggregate (smaller than 150µm) reduces bleeding. Similarly polypropylene micro-fibres are known to reduce bleeding.

If the bleed water is remixed during the finishing of the top surface, a weak top surface will result. To avoid this, the finishing operations can be delayed until the bleed water has evaporated. Conversely, if evaporation of the surface water is faster than the rate of bleed, plastic shrinkage cracking may occur. BS 8500-1: 2015 Table A.9 [c)] states that "Cements or combinations containing more than a mass fraction of 55% ggbs might not be suitable for the wearing surfaces of pavement concrete due to the possibility of surface scaling in the top few millimetres."

In more severe cases, segregation of aggregates can also occur, with the heavier coarse particles moving towards the bottom of the concrete, leaving a cement sand paste layer on the top surface.

Excessive working of a concrete prone to bleeding can prolong bleeding and encourage further aggregate settlement.

Finishing an unformed surface can be adversely effected by bleeding

STEPS IN MANUFACTURE OF CONCREE:

Process of Manufacture of Concrete: It is interesting to note that the ingredients of good concrete and bad concrete are the same.

If meticulous care is not exercised, and good rules are not observed, the resultant concrete is going to be of bad quality.

With the same material if intense care is taken to exercise control at every stage, it will result in good concrete.

The various stages of manufacture of concrete are: (a) Batching (b) Mixing (c) Transporting (d) Placing (e) Compacting (f) Curing (g) Finishing.

Batching :

Volume Batching:

Volume batching is not a good method for proportioning the material because of the difficulty it offers to measure granular material in terms of volume. Volume of moist sand in a loose condition weighs much less than the same volume of dry compacted sand. The effect of bulking should be consider for moist fine aggregate. For unimportant concrete or for any small job, concrete may be batched by volume.

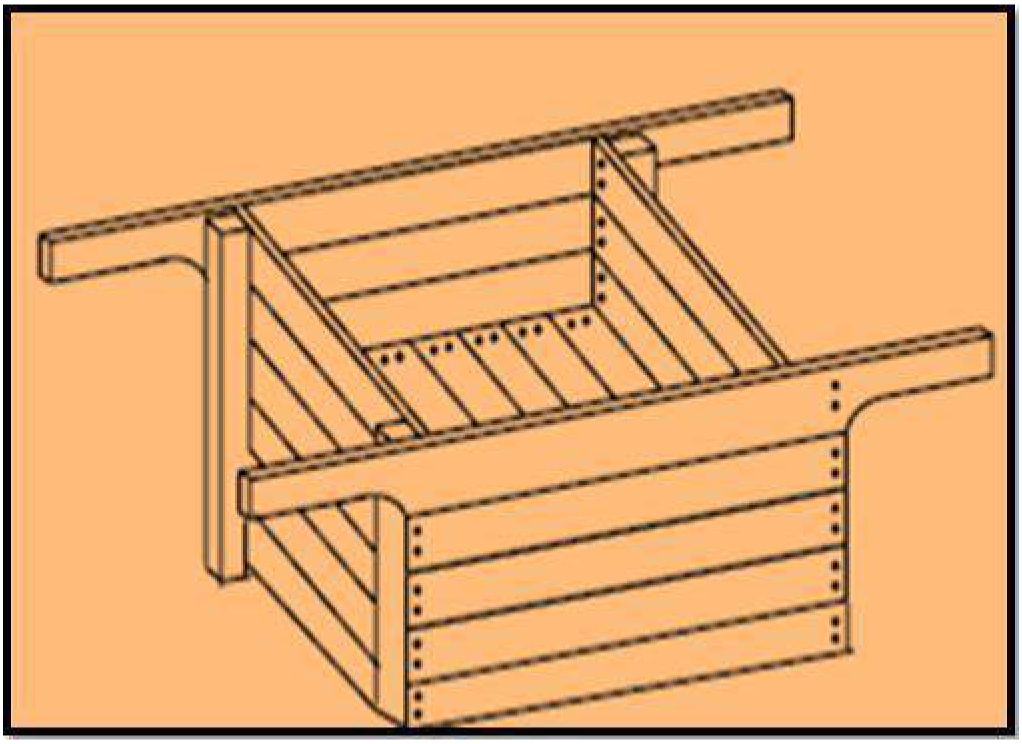


Fig 3.5**Typical gauge box**

Vol. Of gauge box = width(33.33cm) X height(30cm) X depth (35cm)

Weigh batching is the correct method of measuring the materials.

Use of weight system in batching, facilitates accuracy, flexibility and simplicity.

Large weigh batching plants have automatic weighing equipment.

On large work sites, the weigh bucket type of weighing equipment's are used.

Mixing

Thorough mixing of the materials is essential for the production of uniform concrete.

The mixing should ensure that the mass becomes homogeneous, uniform in colour and consistency.

There are two methods adopted for mixing concrete: (i) Hand mixing (ii)Machine mixing

Mixing: Hand mixing

Hand mixing is practised for small scale unimportant concrete works.

As the mixing cannot be thorough and efficient, it is desirable to add 10 per cent more cement to cater for the inferior concrete produced by this method.

Hand mixing should be done over an impervious concrete or brick floor of sufficiently large size to take one bag of cement.

Spread out the measured quantity of coarse aggregate and fine aggregate in alternate layers. Mixing: Hand mixing

Pour the cement on the top of it, and mix them dry by shovel, turning the mixture over and over again until uniformity of colour is achieved.

Water is taken in a water-can fitted with a rose-head and sprinkled over the mixture and simultaneously turned over.

This operation is continued till such time a good uniform, homogeneous concrete is obtained.

Mixing: Machine Mixing

Mixing of concrete is almost invariably carried out by machine, for reinforced concrete work and for medium or large scale mass concrete work

Machine mixing is not only efficient, but also economical, when the quantity of concrete to be produced is large.

They can be classified as batch-mixers and continuous mixers.

Batch mixers produce concrete, batch by batch with time interval, whereas continuous mixers produce concrete continuously without stoppage till such time the plant is working. Mixing: Machine Mixing

In normal concrete work, it is the batch mixers that are used. Batch mixer may be of pan type or drum type.

The drum type may be further classified as tilting, non-tilting, reversing or forced action type. As per I.S. 1791–1985, concrete mixers are designated by a number representing its nominal mixed batch capacity in litres. The following are the standardized sizes of three types:

a. Tilting: 85 T, 100 T, 140 T, 200 T

b. Non-Tilting: 200 NT, 280 NT, 375 NT, 500 NT, 1000 NT

c. Reversing: 200 R, 280 R, 375 R, 500 R and 1000 R

TRANSPORTING: Concrete can be transported by variety of methods and equipment's. The precaution to be taken while transporting concrete is that the homogeneity obtained at the time of mixing should be maintain while being transported to the final place of deposition. The methods adopted for transportation of concrete are ; mortar pan, wheel barrow, hand cart, crane, ropeway and truck mixer and dumpers etc.

PLACING: it is of utmost importance that the concrete must be placed in systematic manner to yield optimum results. The precautions should be taken the methods adopted while placing concrete in the under mention situations.

a) Placing concrete within earth mould.

   Ex: foundation concrete for a wall or column

b) Placing concrete within large earth mould or timber plank formwork

   Ex: road slab and airfield slab

c) Placing concrete Usual form work (Ex: columns, beams & floors)

d) Placing concrete under water.

CURING: Curing is the process of controlling the rate and extent of moisture loss from concrete during cement hydration. It may be either after it has been placed in position (or during the manufacture of concrete products), thereby providing time for the hydration of the cement to occur. Since the hydration of cement does take time – days, and even weeks rather than hours – curing must be undertaken for a reasonable period of time if the concrete is to achieve its potential strength and durability. Curing may also encompass the control of temperature since this affects the rate at which cement hydrates.The curing period may depend on the properties required of the concrete, the purpose for which it is to be used, and the ambient conditions, ie the temperature and relative humidity of the surrounding atmosphere. Curing is designed primarily to keep the concrete moist, by preventing the loss of moisture from the concrete during the period in which it is gaining strength. Curing may be applied in a number of ways and the most appropriate means of curing may be dictated by the site or the construction method.

COMPACTION OF CONCRETE:IT IS the process adopted for expelling the entrapped air from the concrete.

The following methods are adopted for compacting the concrete:

a) Hand compaction
   i) Rodding
   ii) Ramming
   iii) Tamping

b) Compaction by vibration
   i) Internal vibrator(needle vibrator)
   ii) Formwork vibrator(external vibrator)
   iii) Table vibrator
   iv) Platform vibrator
   v) Surface vibrator
   vi) Vibratory roller

c) Compaction by pressure and jolting
d) Compaction by spinning

FINISHING OF CONCRETE: finishing operation is the last operation for making concrete. Finishing may not be applicable where as for the concrete road pavements, airfield pavement or for the flooring of a domestic building, careful finishing is of great importance.

Quality of mixing water:

The water used for the mixing and curing of concrete should be free from injurious amounts of deleterious materials. The unwanted situations, leading to the distress of concrete, have been found to be a result of, among others, the mixing and curing water being of inappropriate quality. Potable water is generally considered satisfactory for mixing concrete. In the case of doubt about the suitability of water, particularly in remote areas or where water is derived from sources not normally utilized for domestic purposes, water should be tested.

TABLE 1: PERMISSIBLE LIMIT FOR SOLIDS AS PER IS 456:2000

Material	Tested as per	Permissible limits Max (in ppm)
Organic	IS 3025 part 18	200
Inorganic	IS 3025 part 18	3000
Sulphates(SO_3)	IS 3025 part 24	400
Chlorides(Cl)	IS 3025 part 32	2000 for P.C.C & 500 for RCC
suspended	IS 3025 part 17	2000

Table I: Recommended limits and possible hazardous effects of dissolved chemical impurities in water

Impurities	Limit	Remarks
NaNO3 and KNO3	No limit available	Sodium and potassium nitrates give strength little inferior to those obtained with sodium chloride.
CaSO4	No limit available	Water saturated with calcium sulfate is satisfactory for the liquid phase in cement paste which is normally saturated or even super-saturated with this compound.

$Ca(NO_3)_2$	1.7% weight of cement	Calcium nitrate added 1.7% weight of cement accelerates setting time and strength reduction.
Na_2SO_4, $MgCl_2$, $MgSO_4$	10,000 ppm	1% concentration of these common ions, exclusive of carbonate and bicarbonate, could be present without much effect on strength.
($FeSO_4$)	No limit available	In mix water, if 0.5, 1, 2, and 4 % weight by water shows 28 days and 3 years tensile strengths which is exceeding 10 and 15% of control specimens.
Zinc oxide	0.01% weight of cement	No significant effect but 0.1% strongly retarded setting time and lowered strength.
Ammonium ion	No limit available	Ammonium chloride increased strength. 0.4, 0.8 and higher percentage by weight of water of ammonium nitrate give same strength as with similar percentage of NaCl in water for making concrete.
Tannic acid	0.5% weight of water	No effect on strength but may have a considerable effect on setting time of concrete.

Table 2.Tolerable concentrations of some impurities in mixing water:

S.no	Impurity	Tolerable concentration
1	Sodium and potassium carbonates and bi-carbonates	1000 ppm(total) if this is exceeded, it is advisable to make tests both for setting time and 28 days strength
2	Chlorides	10000 ppm
3	Sulphuric anhydride	3000 ppm
4	Calcium chloride	2% by weight of cement in pre stressed concrete
5	Sodium iodate, sodium sulphate, sodium botate	Very low
6	Sodium sulphide	Even 100 ppm warrants testing
	Sodium hydroxide	0.5% by weight of cement, provided

7		quick set is not induced.
8	Salt and suspended particles	2000 ppm. Mixing water with a high content of suspended solids should be allowed to stand in a setting basin before use.
9	Total dissolved salts	15000 ppm
10	Organic material	3000 ppm. Water containing humic acid.
11	P^H	Shall not be less than 6

Use of Sea Water for Mixing Concrete

It is advisable, as stated above, to use clean water fit for drinking purposes for making cement concrete. However, at places where sea water is available in abundance and potable water is costly, the **sea water** can be used for making cement concrete. The problem of using **sea water for mixing concrete** has to be studied from the following two aspects:

(1)Strength
(2) Corrosion of reinforcement

(1) Strength:

Below table shows the analysis of average sea water. It contains about 3.50 per cent of dissolved salts. The approximate percentages of various salts are 78 per cent of sodium chloride, 15 per cent of magnesium chloride and magnesium sulphate and the rest 7 per cent of calcium sulphate, potassium sulphate, etc.

COMPOSITION OF AVERAGE SEA WATER

No.	Constituent		Content in gm per litre
1.	Calcium	(Ca)	0.43
2.	Chloride	(Cl_2)	19.80
3.	Magnesium	(Mg)	1.33
4.	Potassium	(K)	0.40
5.	Sodium	(Na)	11.00
6.	Sulphate	(SO_4)	2.76
		Total	35.72

Now all chlorides tend to accelerate the setting of cement and to improve the strength of concrete in early stages. On the other hand, the sulphates tend to retard the setting of cement and to discourage the strength of concrete in early stages.

It is found that the net effect of these two contradictory actions is the fall in strength of concrete to the tune of about 8 to 20 per cent. Hence the ***sea water can be used for mixing cement concrete*** for structures where such fall in strength is permissible or where it is possible to correct the same by adjusting water- cement ratio, cement content in concrete, etc.

The sea water tends to develop dampness and efflorescence. Hence it can be adopted for concrete structures where finishing characteristics are not important or where persistent dampness of the surface is permissible.

***(2) Corrosion of reinforcement**:*

It is found that the sea water does not lead to the corrosion of reinforcement, provided the concrete is dense and there is enough cover to the reinforcement.

The minimum cement content for concrete permanently under sea water should be 3 kN per m^3 and the minimum cover over the reinforcement should be 75 mm. However it is not advisable to take the risk of corrosion of reinforcement for prestressed concrete and hence the sea water should not be used for making prestressed concrete.

Ready Mixed Concrete: A concrete whose constituents are weight-batched at a central batching plant, mixed either at the plant itself or in truck mixers, and then transported to the construction site and delivered in a condition ready to use, is termed as ready mixed concrete.

Advantages of Ready Mixed Concrete:

1. Quality assured concrete:- Concrete is produced under controlled conditions using consistent quality of raw material.
2. High speed of construction- Speed of construction can be vary fast in case RMC is used.
3. Reduction in cement consumption by 10 – 12 % due to better handling and proper mixing. Further reduction is possible if mineral admixtures or cementitious materials are used.
4. Versatility in uses and methods of placing: The mix design of the concrete can be tailor made to suit the placing methods of the contractor.
5. Since ready mixed concrete (RMC) uses bulk cement instead of bagged cement, dust pollution will be reduced and cement will be saved.
6. Conservation of energy and resources because of saving of cement.
7. Environment pollution is reduced due to less production of cement.
8. With better durability of structure, their overall service life increase and there is saving in life-cycle cost.
9. Eliminating or minimizing human error and reduction in dependency on labour.
10. Timely deliveries in large as well as small pours.
11. No need for space for storing the materials like coarse and fine aggregate, cement, water and admixtures.
12. No delay due to site based batching plant erection/ dismantling; no equipment to hire; no depreciation of costs.
13. Reduced noise and air pollution; less consumption of petrol and diesel and less time loss to business.

DISADVANTAGESOF READY MIXED CONCRETE:

- The materials are batched at a central plant, and the mixing begins at that plant, so the traveling time from the plant to the site is critical over longer distances. Some sites are just too far away, however the use of admixtures like retarder can be added.

- Furthermore, access roads and site access have to be able to carry the greater weight of the ready-mix truck plus load. (Green concrete is approx. 2.5 tonne per m^3.) This problem can be overcome by utilizing so-called 'mini mix' companies which use smaller $4m^3$ capacity mixers able to reach more-restricted sites.
- Concrete's limited time span between mixing and curing means that ready-mix should be placed within 210 minutes of batching at the plant. Modern admixtures can modify that time span precisely, however, so the amount and type of admixture added to the mix is very important.

Lightweight Aggregates

Lightweight aggregate is a type of coarse aggregate that is used in the production oflightweight concrete products such as concrete block, structural concrete, and pavement. Most lightweight aggregate is produced from materials such as clay, shale, or slate. Blastfurnace slag, natural pumice, vermiculite, and perlite can be used as substitutes, however. To producelightweight aggregate, the raw material (excluding pumice) is expanded to about twice the originalvolume of the raw material. The expanded material has properties similar to natural aggregate, but is less dense and therefore yields a lighter concrete product.

Applications where lightweight aggregates are used include:

- lightweight concrete masonry
- structural lightweight and semi-lightweight cast-in-place concrete
- low-density precast concrete units
- low-density mortars for radiant heat floor and refractories
- geotechnical low-density engineered fill
- insulating concrete fill
- concrete roofing tile and ballast
- ground cover and soil-less mixes

Lightweight concrete

Lightweight concretes can either be lightweight aggregate concrete, foamed concrete or autoclaved aerated concrete (AAC). Lightweight concrete blocks are often used in house construction.

It can be three methods

1. Aerated concrete

2. No fines concrete

3. Using light weight aggregate

Lightweight aggregate concrete

Lightweight aggregate concrete can be produced using a variety of lightweight aggregates. Lightweight aggregates originate from either:

- Natural materials, like volcanic pumice.
- The thermal treatment of natural raw materials like clay, slate or shale.

- Manufacture from industrial by-products such as fly ash.
- Processing of industrial by-products such as pelletised expanded slab.

The required properties of the lightweight concrete will have a bearing on the best type of lightweight aggregate to use. If little structural requirement, but high thermal insulation properties, are needed then a light, weak aggregate can be used. This will result in relatively low strength concrete.

Cellular concrete

Cellular concrete is a lightweight cement-based material, containing many gas bubbles evenly distributed in the volume, produced by blending and maturing of a mixture of cement, filler, water, agent generating cells.

Fig 3.4. Cellular concrete

By the method of generating the air or gas cells there exist foam concrete and gas concrete. Gas concrete is presented mainly in the form of pre-cast blocks, the majority of its applications however demand it to be cast-in-place.

Cellular concrete is produced with various densities (volume weights) from 250 kg/m³ to 1600 kg/m³. CFC is harder in comparison with traditional insulation materials, especially when chemical and fire resistance is needed.

The specialists of CFC International LLC developed and patented a fundamentally new approach to the preparation and application of aerated concrete in construction. A dry mix of cellular gas concrete was created - Cellular Fibro Concrete ("Fibro" indicates that the cellular concrete is reinforced with synthetic fibres). The dry mix is packed in 25 kg paper bags, 500 kg and 1000 kg big-bags, or transported in mobile silo-bunkers or in special vehicles with built in mixers, directly to the construction sites.

The advantages of using cellular concrete for road construction are:

- Capillary blocking - using cellular concrete within the roadway and the sidewalk reduces significantly the damage from frost heaving during the spring thaw;
- The use of cellular concrete as a base for the sidewalk and the road creates an extremely rigid foundation, thus, prolonging the life of the pavement and reducing maintenance costs;
- Lower costs - cellular concrete, replacing the insulation and bulk materials in construction, requires a much smaller thickness according to its characteristics, so as a result of this there are significant financial savings;
- Easy to use - cellular concrete has a liquid consistency, so it is not afraid of the roughness of the excavation. Monolithic porous concrete can be cast and aligned

exactly to the required thickness;

- Less excavation - cellular concrete typically requires three to four times less thickness than the loose materials (sand, gravel), and therefore reduces equally the depth of the pit;
- Protection from adverse weather conditions - the use of cellular concrete protects the soil from the subgrade softening in precipitation;
- Reduction of external damage - dumping and compacting of loose materials may violate and weaken the base of the soil subgrade. Cellular concrete is poured in liquid form, so no need of packing or vibration.

No-Fines Concrete

No-Fines Concrete is a method of producing light concrete by omitting the fines from conventional concrete. No-fines concrete as the term implies, is a kind of concrete from which the fine aggregate fraction has been omitted. This concrete is made up of only coarse aggregate, cement and water. Very often only single sized coarse aggregate, of size passing through 20 mm retained on 10 mm is used. No-fines concrete is becoming popular because of some of the advantages it possesses over the conventional concrete.

The single sized aggregates make a good no-fines concrete, which in addition to having large voids and hence light in weight, also offers architecturally attractive look.

In some occasions no fines concrete is used in houses because of its good thermal insulation properties. Basically no fines concrete consists of coarse aggregates and cement without any fine aggregates. It is essential that no fines concrete should be designed with a certain amount of voids to enhance thermal insulation. The size of these voids should be large enough to avoid the movement of moisture in the concrete section by capillary action. It is common for no fines concrete to be used as external walls in houses because rains falling on the surface of external walls can only penetrate a short horizontal distance and then falls to the bottom of the walls. The use of no fines concrete guarantees good thermal insulation of the house.

High Density Concrete

High density concrete is a concrete having a density in the range of 6000 to 6400 kg/cu.m. High density concrete is also known as Heavy weight concrete. High density concrete is mainly used for the purpose of radiation shielding, for counterweights and other uses where high density is required.

Properties of High Density Concrete:

Properties of High Density Aggregates and Concrete

Type of aggregate	Fixed-water,* percent by weight	Aggregate relative density	Aggregate bulk density, kg/m³ (pcf)	Concrete density, kg/m³ (pcf)
Goethite	10–11	3.4–3.7	2080–2240 (130–140)	2880–3200 (180–200)
Limonite**	8–9	3.4–4.0	2080–2400 (130–150)	2880–3360 (180–210)
Barite	0	4.0–4.6	2320–2560 (145–160)	3360–3680 (210–230)
Ilmenite	†	4.3–4.8	2560–2700 (160–170)	3520–3850 (220–240)
Hematite	†	4.9–5.3	2880–3200 (180–200)	3850–4170 (240–260)
Magnetite	†	4.2–5.2	2400–3040 (150–190)	3360–4170 (210–260)
Ferrophosphorus	0	5.8–6.8	3200–4160 (200–260)	4080–5290 (255–330)
Steel punchings or shot	0	6.2–7.8	3860–4650 (230–290)	4650–6090 (290–380)

* Water retained or chemically bound in aggregates.
** Test data not available.
† Aggregates may be combined with limonite to produce fixed-water contents varying from about ½% to 5%.

Fiber-reinforced concrete

Fiber-reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers – each of which lend varying properties to the concrete. In addition, the character of fiber-reinforced concrete changes with varying concretes, fiber materials, geometries, distribution, orientation, and densities.

The concept of using fibers or as reinforcement is not new. Fibers have been used as reinforcement since ancient times. Historically, horsehair was used in mortar and straw in mudbricks. In the 1900s, asbestos fibers were used in concrete. In the 1950s, the concept of compositematerials came into being and fiber-reinforced concrete was one of the topics of interest. Once the healthrisks associated with asbestos were discovered, there was a need to find a replacement for the substance in concrete and other building materials. By the 1960s, steel, glass (GFRC), and synthetic fibers such as polypropylene fibers were used in concrete. Research into new fiber-reinforced concretes continues today.

DIFFERENT TYPES OF FIBRES

1. Steel fibres
2. Glass fibre
3. Plastic fibres
4. Polypropylene fibres
5. Asbestos fibre
6. Carbon fibre etc.

FACTORS AFFECTING PROPERTIES OF FRC:

1. Relative fibre matrix stiffness
2. Volume of fibres
3. Aspect ratio of the fibres
4. Orientation of fibres
5. Workability and compaction of concrete
6. Size of coarse aggregate
7. Mixing

Benefits

Polypropylene and Nylon fibers can:

- Improve mix cohesion, improving pump ability over long distances
- Improve freeze-thaw resistance
- Improve resistance to explosive spalling in case of a severe fire
- Improve impact resistance– and abrasion–resistance
- Increase resistance to plastic shrinkage during curing
- Improve structural strength
- Reduce steel reinforcement requirements
- Improve ductility
- Reduce crack widths and control the crack widths tightly, thus improving durability

Steel fibers can:

- Improve structural strength
- Reduce steel reinforcement requirements
- Reduce crack widths and control the crack widths tightly, thus improving durability
- Improve impact– and abrasion–resistance
- Improve freeze-thaw resistance

Polymer concrete:

Polymer concretes are a type of concrete that use polymers to replace lime-type cements as a binder. In some cases the polymer is used in addition to Portland cement to form Polymer Cement Concrete (PCC) or Polymer Modified Concrete (PMC)

In polymer concrete, thermoplastic polymers may be used, but more typically thermosetting resins are used as the principal polymer component due to their high thermal stability and resistance to a wide variety of chemicals. Polymer concrete is also composed of aggregates that include silica, quartz, granite, limestone, and other high quality material. The aggregate must be of good quality, free of dust and other debris, and dry. Failure to fulfill these criteria can reduce the bond strength between the polymer binder and the aggregate.

Uses

Polymer concrete may be used for new construction or repairing of old concrete. The adhesive properties of polymer concrete allow repair of both polymer and conventional cement-based concretes. The low permeability and corrosive resistance of polymer concrete allows it to be used in swimming pools, sewer structure applications, drainage channels, electrolytic cells for base metal recovery, and other structures that contain liquids or corrosive chemicals. It is especially suited to the construction and rehabilitation of manholes due to their ability to withstand toxic and corrosive sewer gases and bacteria commonly found in sewer systems. Unlike traditional concrete structures, polymer concrete requires no coating or welding of PVC-protected seams.It can also be used as a bonded wearing course for asphalt pavement, for higher durability and higher strength upon a concrete substrate.

Polymer concrete has historically not been widely adopted due to the high costs and difficulty associated with traditional manufacturing techniques. However, recent progress has led to significant reductions in cost, meaning that the use of polymer concrete is gradually becoming more widespread.

Properties

The exact properties depend on the mixture, polymer, aggregate used etc. etc. but generally speaking with mixtures used:

- The binder is more expensive than cement
- Significantly greater tensile strength than unreinforced Portland concrete (since plastic is 'stickier' than cement and has reasonable tensile strength)
- Similar or greater compressive strength to Portland concrete
- Much faster curing
- Good adhesion to most surfaces, including to reinforcements
- Good long-term durability with respect to freeze and thaw cycles
- Low permeability to water and aggressive solutions
- Good chemical resistance
- Good resistance against corrosion
- Lighter weight (slightly less dense than traditional concrete, depending on the resin content of the mix)
- May be vibrated to fill voids in forms
- Allows use of regular form-release agents (in some applications)
- Dielectric
- Product hard to manipulate with conventional tools such as drills and presses due to its density. Recommend getting pre-modified product from the manufacturer
- Small boxes are more costly when compared to its precast counterpart however pre cast concretes induction of stacking or steel covers quickly bridge the gap.

TYPES OF POLYMER CONCRETE

1. Polymer impregnated concrete (PIC)
2. Polymer cement concrete (PCC)
3. Polymer concrete (PC)

   Polymer impregnated concrete (PIC): Polymer impregnated concrete is one of the widely used polymer composite. It is nothing but a precast conventional concrete, cured and dried in oven, or by dielectric heating from which the air in the open cell is removed by vacuum. Then a low viscosity monomer is diffused through the open cell and polymerized by using radiation, application of heat or by chemical initiation Polymer Impregnated Concrete (PIC)

   Polymer cement concrete (PCC): Polymer cement concrete is made by mixing cement, aggregates, water and monomer. Such plastic mixture is cast in moulds, cured, dried and polymerized. The monomers that are used in PCC are: (a) Polyster-styrene. (b) Epoxy-styrene. (c) Furans. (d) Vinylidene Chloride. Polymer Cement Concrete (PCC)

   Polymer concrete (PC): Polymer concrete is an aggregate bound with a polymer binder instead of Portland cement as in conventional concrete. The main technique in producing PC is to minimize void volume in the aggregate mass so as to reduce the quantity of polymer needed for binding the aggregates. This is achieved by properly grading and mixing the aggregates to attain the maximum density and minimum void volume. The graded aggregates are prepacked and vibrated in a moulds. Monomer is then diffused up through the aggregates and polymerization is initiated by radiation or chemical means. A Silone coupling agent is added to the monomer to improve the bond strength between the polymer and the aggregate. In case polyester resins are used no polymerization is required.

HIGH PERFORMANCE CONCRETE: High performance concrete is a concrete mixture, which possess high durability and high strength when compared to conventional concrete. This concrete contains one or more of cementious materials such as fly ash, Silica fume or ground granulated blast furnace slag and usually a super plasticizer. The term 'high performance' is somewhat pretentious because the essential feature of this concrete is that it's ingredients and proportions are specifically chosen so as to have particularly appropriate properties for the expected use of the structure such as high strength and low permeability. Hence High performance concrete is not a special type of concrete. It comprises of the same materials as that of the conventional cement concrete. The use of some mineral and chemical admixtures like Silica fume and Super plasticizer enhance the strength, durability and workability qualities to a very high extent.

High Performance concrete works out to be economical, even though it's initial cost is higher than that of conventional concrete because the use of High Performance concrete in construction enhances the service life of the structure and the structure suffers less damage which would reduce overall costs.

SELF CONSOLIDATING CONCRETE: Self-consolidating concrete or self-compacting concrete is a concrete mix which has a low yield stress, high deformability, good segregation resistance (prevents separation of particles in the mix), and moderate viscosity (necessary to ensure uniform suspension of solid particles during transportation, placement (without external compaction), and thereafter until the concrete sets).

In everyday terms, when poured, SCC is an extremely fluid mix with the following distinctive practical features - it flows very easily within and around the formwork, can flow through obstructions and around corners ("passing ability"), is close to self-levelling (although not actually self-levelling), does not require vibration or tamping after pouring, and follows the shape and surface texture of a mold (or form) very closely once set. As a result, pouring SCC is also much less labor-intensive compared to standard concrete mixes. Once poured, SCC is usually similar to standard concrete in terms of its setting and curing time (gaining strength), and strength. SCC does not use a high proportion of water to become fluid - in fact SCC may contain less water than standard concretes. Instead, SCC gains its fluid properties from an unusually high proportion of fine aggregate, such as sand (typically 50%), combined with super plasticizers (additives that ensure particles disperse and do not settle in the fluid mix) and viscosity-enhancing admixtures (VEA).

SCC can be used for casting heavily reinforced sections, places where there can be no access to vibrators for compaction and in complex shapes of formwork which may otherwise be impossible to cast, giving a far superior surface than conventional concrete. The relatively high cost of material used in such concrete continues to hinder its widespread use in various segments of the construction industry, including commercial construction, however the productivity economics take over in achieving favorable performance benefits and works out to be economical in pre-cast industry.

FERRO CEMENT CASTING AND GUNTING TECHNIQUES AND APPLICATIONS

Ferro cement is a thin construction element with thickness in the order of 10-25 mm (3/8–1 in.) and uses rich cement mortar; no coarse aggregate is used; and the reinforcement consists of one or more layers of continuous/ small diameter steel wire/ weld mesh netting. It requires no skilled labour for casting, and employs only little or no formwork. In ferrocement, cement matrix does not crack since cracking forces are taken over by wire mesh reinforcement immediately below the surface

GUNTING: The process of gunting can be adopted for applying the mortar to the wire mesh system. This process applied with experienced gunman can give good compact and uniform surface. This appears to be suitable process for mass production of ferrocement prefabricated units.

Following are the advantages of guniting

- The high compressive strength is obtained. Strength of about 56 to 70 n/mm^2 at 28 days is generally obtained.
- The high impermeability is achieved.
- The repairs are carried out in any situation in a short time.

Properties of Ferro cement:

- Highly versatile form of reinforced concrete.
- It's a type of thin reinforced concrete construction, in which large amount of small diameter wire meshes uniformly throughout the cross section.
- Mesh may be metal or suitable material.
- Instead of concrete Portland cement mortar is used.
- Strength depends on two factors quality of sand/cement mortar mix and quantity of reinforcing materials used.

Advantages and Disadvantages of Ferro cement

Advantages:

- Basic raw materials are readily available in most countries.
- Fabricated into any desired shape.
- Low labour skill required.
- Ease of construction, low weight and long lifetime.
- Low construction material cost.
- Better resistance against earthquake.

Disadvantages:

- Structures made of it can be punctured by collision with pointed objects.
- Corrosion of the reinforcing materials due to the incomplete coverage of metal by mortar.
- It is difficult to fasten to Ferro cement with bolts, screws, welding and nail etc.
- Large no of labors required.
- Cost of semi-skilled and unskilled labors is high.
- Tying rods and mesh together is especially tedious and time consuming.

Process of Ferro cements Construction:

- Fabricating the skeletal framing system.
- Applying rods and meshes.
- Plastering.
- Curing

Applications of Ferro cements in Construction:

- Housing
- Marine
- Agricultural
- Rural Energy
- Anticorrosive Membrane Treatment.
- Miscellaneous.

Assignment-Cum-Tutorial Questions

A. Questions testing the remembering / understanding level of students

I) Objective Questions

1. In slump test for determining workability of concrete, the slump is expressed
   (a) Metres

   (b) centimetres

(c) millimetres

(d) kilometres

2. The concrete having a slump of 6.0 cm is said to be
   (a) Plastic

   (b) semi plastic

   (c) earth

   (d) dry

3. The dimensions of the slump cone apparatus is
   (a)10cmx20cmx30cm
   (b) 20cmx10cmx30cm
   (c) 5cmx10cmx15cm
   (d) 10cmx10cmx10cm

4. Bleeding of concrete is said to occur occurs when

   (a) fine particles settle down at the bottom

   (b) fine particles collect at some places in the structure

   (c) coarse particles gets separated from finer materials

   (d) excess water comes upon the surface

5. Segregation in concrete occurs in when _________

   (a) cement gets separated from mixture due to excess water

   (b) cement fails to give adequate binding quality

   (c) water is driven out of concrete at a faster rate

   (d) coarse aggregate tries to separate out

6. A compaction factor of 0.85 for a sample indicates

   (a) very good workability (b) good work ability

   (c) a mix of medium workability (d) a mix of low workability

7.The units for vee-bee consistometer test

   (a) mm (b) cm (c) hours (d) secs

8. a compacting factor of concrete 0.80 then the degree of workability is

   (a) very low (b) low (c) medium (d) high

9. a compacting factor of concrete 0.85 then the degree of workability is

(a) very low (b) low (c) medium (d) high

10. a compacting factor of concrete 0.93 then the degree of workability is

(a) very low (b) low (c) medium (d) high

II) Descriptive Questions

1. Define workability.
2. Define setting time of concrete.
3. Define segregation and bleeding.
4. What is RMC plant and mention any two advantages and disadvantages.
5. Define gunting.
6. What are the applications of ferrocement products.
7. Define FRC and factors effecting on FRC.

B. Questions testing the ability of students in applying the concepts.

I) Multiple Choice Questions:

1. If the value of slump is 25-75 mm then the degree of workability is

(a) very low (b) low (c) medium (d) high

2. If the value of slump is 50-100 mm then the degree of workability is

(a) very low (b) low (c) medium (d) high

3. If the value of slump is 100-150 mm then the degree of workability is

(a) very low (b) low (c) medium (d) high

4. Measurement of workability of concrete by

(a) slump test (b) compacting factor test

(c) flow test (d) vee-bee consistometer test (e) all

5. The type failures of concrete occurs in workability by slump cone test

(a) true slump (b) shear (c) collapse (d) any of the above

6. A concrete is said to be workable if

(a) it shows signs of bleeding

(b) it shows signs of segregation

(c) it can be easily mixed, placed & compacted

(d) it contains more than optimum quantity of water

7. Concrete is considered as unsuitable for compaction by vibration if it is

(a) plastic (b) semi plastic (c) dry (d) moist earth

8. If a concrete gives more strength than the designed value

(a) cement content is reduced

(b) water % is increased

(c) proportion of sand is changed

(d) water cement ratio is changed

9. According to ISI the full strength of concrete is achieved after

(a) 7 days (b) 14 days (c) 21 days (d) 28 days

10. The strength of concrete is decreased by

(a) reversible stress (b) vibration (c) direct impact (d) all of the above

II) Descriptive Questions

1. What is Workability and explain various factors influencing the Workability?
2. Define workability. What are the different methods for measuring the workability?
3. How is the compacting factor measured?
4. What is segregation and bleeding?
5. What are the different steps in the manufacture of concrete?
6. What are the Factors affecting properties of F.R.C?
7. Explain the following
   a) Cellular concrete
   b) Polymer concrete
   c) High performance concrete
   d) No fines concrete
   e) light weight aggregate concrete
   f) Self consolidating concrete
   g) High density concrete
   h) fibre reinforced concrete

C. Questions testing the analyzing /evaluating ability of students

1. How do you select the suitability of workability tests of different concretes?

2. Analyse the effect of time and temperature on workability.

3. How do you control the segregation and bleeding on workability?

4. Whether sea water can be used for concrete mix or not? Discuss

5. Discuss the suitability of light weight aggregate in construction.

6. Analyse the advantages of steel fibres in construction.

D. GATE/ Competitive oriented bits

1. The P^H value of water for making concrete is

(a) 6-8 (b) 7-9 (c) 5-8 (d) 7-11

2. The sulphate (SO_3) concentration in water for making concrete should not be more than

(a) 400 ppm (b) 3000 ppm (c) 5000 ppm (d) 10000 ppm

3. Organic matter in water for making concrete should not be more than

(a) 200 ppm (b) 2000 ppm (c) 5000 ppm (d) 10000 ppm

UNIT IV

CONCRETE TECHNOLOGY

Hardened Concrete & Testing of hardened concrete

Objective: To know the properties of **Hardened Concrete**

Syllabus: Hardened Concrete: Water / Cement Ratio-Abram's Law-Gel space Ratio-Nature Of Strength Of Concrete-Maturity Concept-Strength In Tension & Compression-Factors Affecting Strength-Relation Between Compression & Tensile Strength-Curing

Testing Of Hardened Concrete: Compression Tests-Tension Tests-Factors Affecting Strength-Flexure Tests-Splitting Tests-Non Destructive Testing Methods

Learning outcomes:

Students will be able to

(i) Enumerate the properties of Hardened concrete
(ii) Conduct the tests in Hardened concrete
(iii) Apply the knowledge of "factors affecting hardened concrete"
(iv) Explain the relation between Compression & Tensile Strength

Introduction

Strength of hardened concrete Strength is defined as the ability of a material to resist stress without failure. The failure of concrete is due to cracking. Under direct tension, concrete failure is due to the propagation of a single major crack. In compression, failure involves the propagation of a large number of cracks, leading to a mode of disintegration commonly referred to as 'crushing'. The strength is the property generally specified in construction design and quality control, for the following reasons:

(1) It is relatively easy to measure, and

(2) Other properties are related to the strength and can be deduced from strength data.

The 28-day compressive strength of concrete determined by a standard uniaxial compression test is accepted universally as a general index of concrete strength.

Strength of concrete is its resistance to rupture. The cohesion and internal friction developed by concrete in resisting failure is related to more or less a single parameter that water cement ratio.

Water cement ratio: The water-cement ratio is one of the most important aspect when it comes to maintaining the strength of Concrete. The ratio depends on the grade of concrete and the structure size. We generally prefer a W/C ratio of 0.4 to 0.6, but it can be decreased in case of high grade concrete, we reduce the amount of water and use plasticizers instead.

W/C ratio affects the workability of concrete and thus should be taken into careful consideration. Also, if the ratio exceeds the normal value, segregation of concrete occurs and the coarse aggregate settles at the bottom, thus affecting the strength of concrete greatly.

In abrams presented his classic law in the form:

x

Where x= w/c ratio by volume and for 28 days results the constants A and B are 14000 lbs/sq.in. and 7 respectively.

abrams water cement ratio law states that the strength of concrete is only dependent upon w/c ratio provided the mix is workable.

GEL/SPACE RATIO

As propounded by Duff Abram's many research workers commented on the validity of water/cement ratio law. They have focused on a few of the limitations of the water/ cement ratio law and argued that Abram's water/cement ratio law can only be called a rule and not a law because Abram's' statement does not include many qualifications necessary for its validity to call it a law. Some of the limitations are that the strength at any water/cement ratio depends on the following things.

1. Degree of hydration
2. Chemical and Physical properties
3. Thetemperatureat which the hydration takes place
4. Air content (in case of air entrained concrete)
5. the change in the effective water/cement ratio and the formation of fissures and cracks due to bleeding or shrinkage

Instead of relating the strength to water/cement ratio, the strength can be more correctly related to the solid products of hydration of cement to the space available for formation of this product. Powers and Brown yard have established the relationship between the strength and gel/space ratio. This ratio is defined as the ratio of the volume of the hydrated cement paste to the sum of volumes of the hydrated cement and of the capillary pores.

Power's experiment showed that the strength of concrete bears a specific relationship with the gel/space ratio. He found the relationship to be $S=240 * x^3$, where S is the strength of the concrete and x is the gel/space ratio and 240 represents the intrinsic strength of the gel in MPa for the type of cement and specimen used.
The strength calculated by Power's expression holds good for an ideal case.
The fig. below shows the relationship between strength and gel/space ratio. It is pointed out that the relationship between the strength and water/cement ratio will hold.

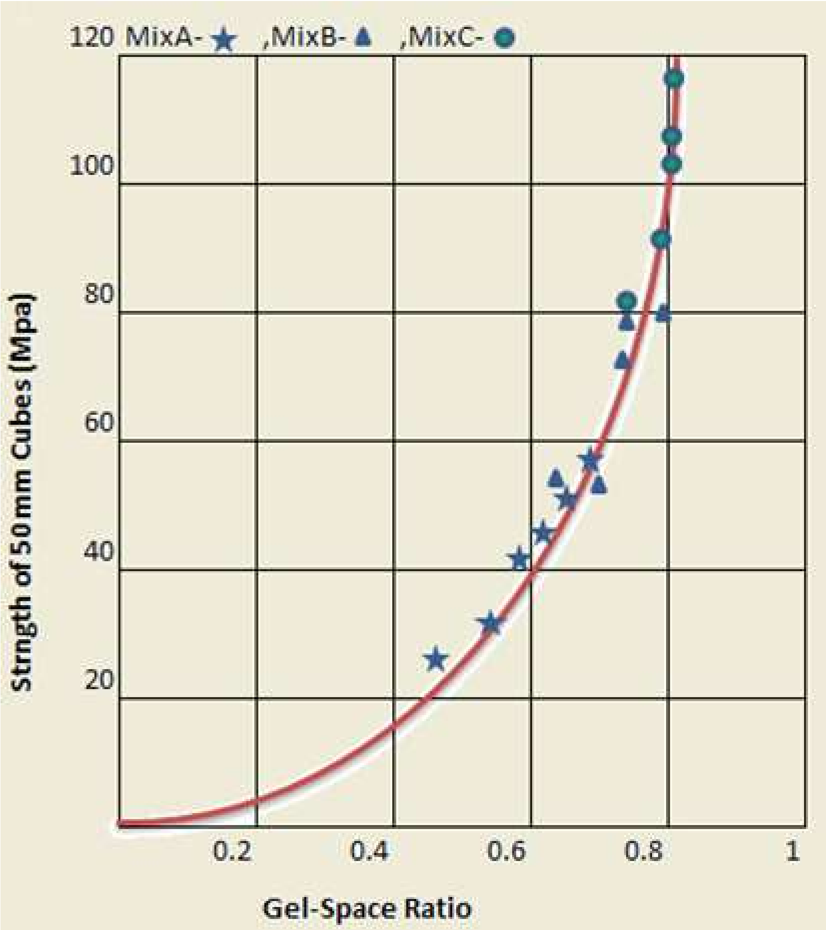


Fig 4.1 Relation between strength & gel space ratio

Nature of strength of concrete: The paramount influence of voids in concrete on its strength has been repeatedly mentioned, and it should be possible to relate this factor to the actual mechanism of failure. For this purpose, concrete is considered to be a brittle material, even though it exhibits a small amount of plastic action, as fracture under static loading takes place at a moderately low total strain; a strain of 0.001 to 0.005 at failure has been suggested as the limit of brittle behaviour. High strength concrete is more brittle than normal strength concrete but there is no quantitative method of expressing the brittleness of concrete whose behaviour in practice falls between the brittle and the ductile types.

Maturity of concrete:

Strength development in concrete occurs due to the hydration reaction between cement and water. The rate of strength development can depend upon several factors including curing conditions (temperature and age), water-to-cement ratio, type and source of cement, etc. The curing conditions are known to have the greatest effect on the rate of strength development, especially the concrete temperature (2 to 9) for a given mixture of concrete. In general, the rate of strength gain for concrete cured at high temperatures is much greater compared to lower temperatures, especially at early ages.

maturity= $\sum$ (time X temperature)

the temperature is reckoned from an origin laying between -12 and -10^{0}C. it was experimentally found that the hydration of concrete continuous to take place up to about -11^{0}C. therefore -11^{0}C is taken as a datum line for computing maturity.

we can calculate the percentage strength of identical concrete at any other maturity by using the following equation

$$19{,}800^0\ \mathrm{Ch.} = A + B \log_{10} (\mathrm{maturity}/10^3)$$

the values of coefficients, A and B depend on the strength level of concrete. the values are given below Table.1

Strength after 28 days at 18^0 C (maturity of 19, 800^0 Ch): Mpa	A	B
Less than 17.5	10	68
17.5 - 35.0	21	61
35.0 - 52.5	32	54
52.5 - 70.0	42	46.5

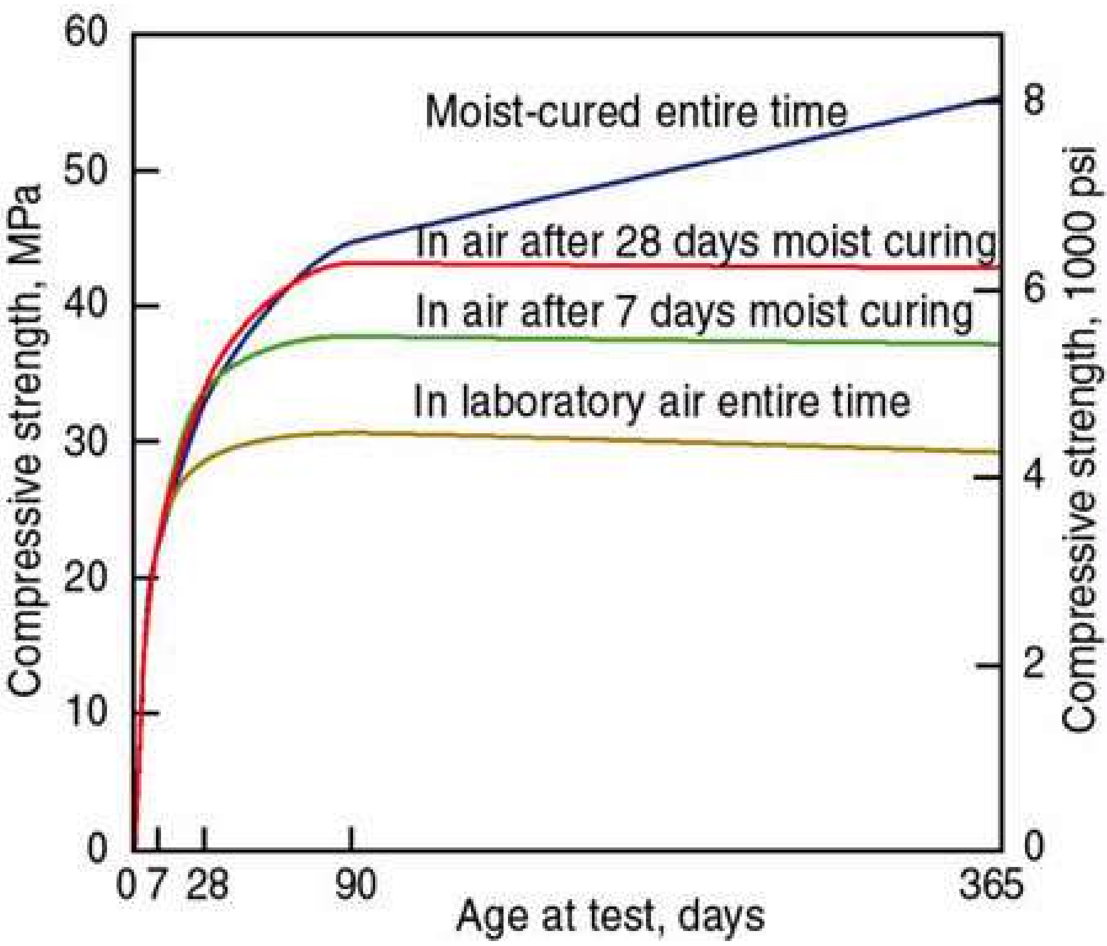


Fig 4.2. Relation between compressive strength & age

FACTORS AFFECTING CONCRETE STRENGTH

Concrete strength is effected by many factors, such as quality of raw materials, water/cement ratio, coarse/fine aggregate ratio, age of concrete, compaction of concrete, temperature, relative humidity and curing of concrete.

1. Quality of Raw Materials:

Cement: Provided the cement conforms with the appropriate standard and it has been stored correctly (i.e. in dry conditions), it should be suitable for use in concrete.

Aggregates: Quality of aggregates, its size, shape, texture, strength etc determines the strength of concrete. The presence of salts (chlorides and sulphates), silt and clay also reduces the strength of concrete.

Water: frequently the quality of the water is covered by a clause stating "..the water should be fit for drinking..". This criterion though is not absolute and reference should be made to respective codes for testing of water construction purpose.

2. Water / Cement Ratio:

The relation between water cement ratio and strength of concrete is shown in the plot as shown below:

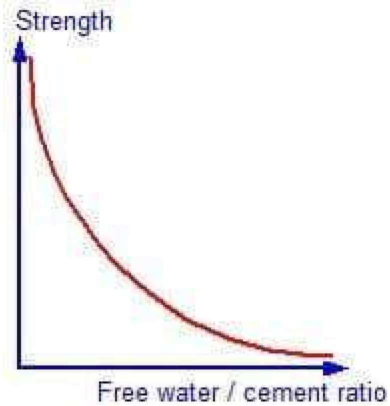


Fig.4.3 Relation between strength &W/C ratio

The higher the water/cement ratio, the greater the initial spacing between the cement grains and the greater the volume of residual voids not filled by hydration products.

There is one thing missing on the graph. For a given cement content, the workability of the concrete is reduced if the water/cement ratio is reduced. A lower water cement ratio means less water, or more cement and lower workability.

However if the workability becomes too low the concrete becomes difficult to compact and the strength reduces. For a given set of materials and environment conditions, the strength at any age depends only on the water-cement ratio, providing full compaction can be achieved.

3. Coarse / fine aggregate ratio:

Following points should be noted for coarse/fine aggregate ratio:

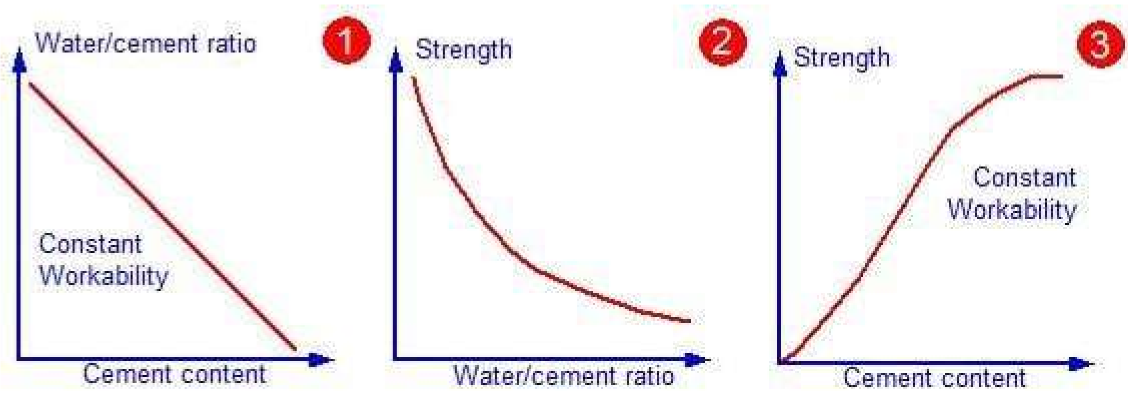
- If the proportion of fines is increased in relation to the coarse aggregate, the overall aggregate surface area will increase.
- If the surface area of the aggregate has increased, the water demand will also increase.
- Assuming the water demand has increased, the water cement ratio will increase.
- Since the water cement ratio has increased, the compressive strength will decrease.

4. Aggregate / Cement Ratio:

Following points must be noted for aggregate cement ratio:

- If the volume remains the same and the proportion of cement in relation to that of sand is increased the surface area of the solid will increase.
- If the surface area of the solids has increased, the water demand will stay the same for the constant workability.
- Assuming an increase in cement content for no increase in water demand, the water cement ratio will decrease.
- If the water cement ratio reduces, the strength of the concrete will increase.

The influence of cement content on workability and strength is an important one to remember and can be summarized as follows:



1. For a given workability an increase in the proportion of cement in a mix has little effect on the water demand and results in a reduction in the water/cement ratio.

2. The reduction in water/cement ratio leads to an increase in strength of concrete.

3. Therefore, for a given workability an increase in the cement content results in an increase in strength of concrete.

5. Age of concrete:

The degree of hydration is synonymous with the age of concrete provided the concrete has not been allowed to dry out or the temperature is too low.

In theory, provided the concrete is not allowed to dry out, then it wil always be increasing albeit at an ever reducing rate. For convenience and for most practical applications, it is generally accepted that the majority of the strength has been achieved by 28 days.

6. Compaction of concrete:

Any entrapped air resulting from inadequate compaction of the plastic concrete will lead to a reduction in strength. If there was 10% trapped air in the concrete, the strength will fall down in the range of 30 to 40%.

7. Temperature:

The rate of hydration reaction is temperature dependent. If the temperature increases the reaction also increases. This means that the concrete kept at higher temperature will gain strength more quickly than a similar concrete kept at a lower temperature.

However, the final strength of the concrete kept at the higher temperature will be lower. This is because the physical form of the hardened cement paste is less well structured and more porous when hydration proceeds at faster rate.

This is an important point to remember because temperature has a similar but more pronounced detrimental effect on permeability of the concrete.

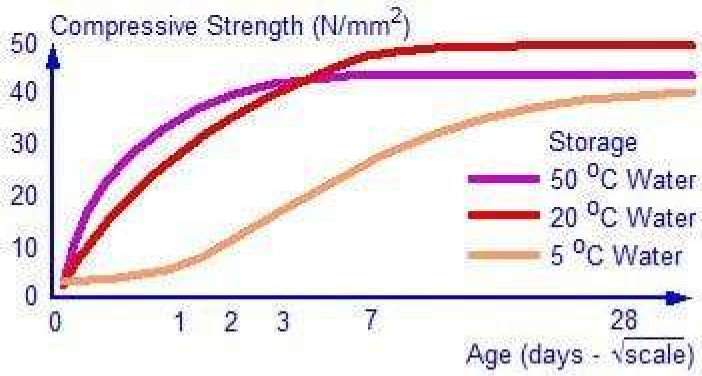
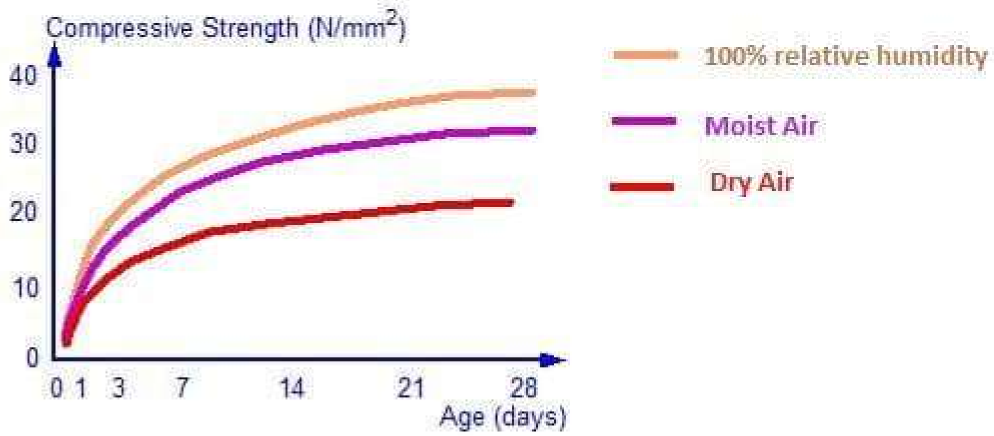


Fig 4.4.Temprature effect

8. Relative humidity:

If the concrete is allowed to dry out, the hydration reaction will stop. The hydration reaction cannot proceed without moisture. The three curves shows the strength development of similar concretes exposed to different conditions.



9. Curing:

It should be clear from what has been said above that the detrimental effects of storage of concrete in a dry environment can be reduced if the concrete is adequately cured to prevent excessive moisture loss.

<u>Curing of concrete:</u>

Curing is the name given to procedures used for promoting the hydration of cement, and consists of a control of temperature and of the moisture movement from and into the concrete. In order to obtain good concrete, the placing of an appropriate mix must be followed by curing in a suitable environment during the early stages of hardening.

It must be stressed that, for a satisfactory development of strength, it is not necessary for all the cement to hydrate and the quality of concrete depends primarily on the gel/space ratio of the paste. If, however, the water-filled space in fresh concrete is greater than the volume that can be filled by the products of hydration, greater hydration will lead to a higher strength and a lower permeability.

Fig. 6.1 1: Influen ce of moi st curing on the stre ngth of c oncrete w ith a water cement r tio of 0.5 0.

Methods of curing:

- Shading concrete work
- Covering concrete surfaces with hessian or gunny bags
- Sprinkling of water
- Ponding method
- Membrane curing
- Steam curing

1. SHADING OF CONCRETE WORK

The object of shading concrete work is to prevent the evaporation of water from the surface even before setting. This is adopted mainly in case of large concrete surfaces such as road slabs. This is essential in dry weather to protect the concrete from heat, direct sun rays and wind. It also protects the surface from rain. In cold weather shading helps in preserving the heat of hydration of cement thereby preventing freezing of concrete under mild frost conditions. Shading may be achieved by using canvas stretched on frames. This method has a limited application only.

2. COVERING CONCRETE SURFACES WITH HESSIAN OR GUNNY BAGS

This is a widely used method of curing, particularly for structural concrete. Thus exposed surface of concrete is prevented from drying out by covering it with hessian, canvas or empty cement bags. The covering over vertical and sloping surfaces should be secured properly. These are periodically wetted. The interval of wetting will depend upon the rate of evaporation of water. It should be ensured that the surface of concrete is not allowed to dry even for a short time during the curing period. Special arrangements for keeping the surface wet must be made at nights and on holidays.

3. SPRINKLING OF WATER

Sprinkling of water continuously on the concrete surface provides an efficient curing. It is mostly used for curing floor slabs. The concrete should be allowed to set sufficiently before sprinkling is started. The spray can be obtained from a perforated plastic box. On small jobs sprinkling of water may be done by hand. Vertical and sloping surfaces can be kept continuously wet by sprinkling water on top surfaces and allowing it to run down between the forms and the concrete. For this method of curing the water requirement is higher.

4. PONDING METHOD

This is the best method of curing. It is suitable for curing horizontal surfaces such as floors, roof slabs, road and air field pavements. The horizontal top surfaces of beams can also be ponded. After placing the concrete, its exposed surface is first covered with moist hessian or canvas. After 24 hours, these covers are removed and small ponds of clay or sand are built across and along the pavements. The area is thus divided into a number of rectangles. The water is filled between the ponds. The filling of water in these ponds is done twice or thrice a day, depending upon the atmospheric conditions. Though this method is very efficient, the water requirement is very heavy. Ponds easily break and water flows out. After curing it is difficult to clean the clay.

5. MEMBRANE CURING

The method of curing described above come under the category of moist curing. Another method of curing is to cover the wetted concrete surface by a layer of water proof material, which is kept in contact with the concrete surface of seven days. This method of curing is termed as membrane curing. A membrane will prevent the evaporation of water from the concrete. The membrane can be either in solid or liquid form. They are also known as sealing compounds. Bituminised water proof papers, wax emulsions, bitumen emulsions and plastic films are the common types of membrane used.

Whenever bitumen is applied over the surface for curing, it should be done only after 24 hours curing with gunny bags. The surface is allowed to dry out so that loose water is not visible and then the liquid asphalt sprayed throughout. The moisture in the concrete is thus preserved. It is quite enough for curing.

This method of curing does not need constant supervision. It is adopted with advantage at places where water is not available in sufficient quantity for wet curing. This method of curing is not efficient as compared with wet curing because rate of hydration is less. Moreover the strength of concrete cured by any membrane is less than the concrete which is moist cured. When membrane is damaged the curing is badly affected.

6. STEAM CURING

Steam curing and hot water curing is sometimes adopted. With these methods of curing, the strength development of concrete is very rapid.

These methods can best be used in pre cast concrete work. In steam curing the temperature of steam should be restricted to a maximum of 75^0C as in the absence of proper humidity (about 90%) the concrete may dry too soon. In case of hot water curing, temperature may be raised to any limit, ay 100^0C.

At this temperature, the development of strength is about 70% of 28 days strength after 4 to 5 hours. In both cases, the temperature should be fully controlled to avoid non-uniformity. The concrete should be prevented from rapid drying and cooling which would form cracks.

RELATION BETWEEN COMPRESSION & TENSILE STRENGTH:

In reinforced concrete construction the strength of the concrete in compression is only taken into consideration. The tensile strength of concrete is generally not taken into consideration. But the design of concrete pavement slabs is often based on the flexural strength of concrete. Therefore, it is necessary to assess the flexural strength of concrete either from the comp. Strength or independently.

As measurements and control of comp. Strength in field are easier and more convient, it has been customary to find out the compressive strength for different conditions and to correlate this comp. Strength to flexural strength. Having established a satisfactory relationship between flexural and comp. Strength, pavement, can be designed for a specified flexural strength value, or this value could be used in any other situations when required.

it is seen that strength of concrete in compression and tension (both direct tension and flexural tension) are closely related, but the relationship is not of the type of direct proportionality. the ratio of the two strengths depends on general level of strength of concrete. in other words, for higher compressive strength concrete shows higher tensile strength, but the rate of increase of tensile strength is of decreasing order.

from the extensive study, carried out at central road research laboratory (CRRI) the following statistical relationship between tensile strength and compressive strength were established.

i) $y=15.3x-9.00$ for 20mm maximum size aggregate

ii) $y=14.1x-10.4$ for 20mm maximum size natural aggregate

iii) $y=9.9x-0.55$ for 40mm maximum size crushed aggregate

iv) $y=9.8x-2.52$ for 40mm maximum size natural gravel.

where y is the comp. strength of concrete Mpa and x is the flexural and comp. strength of concrete.

$$y=11x-3.4$$

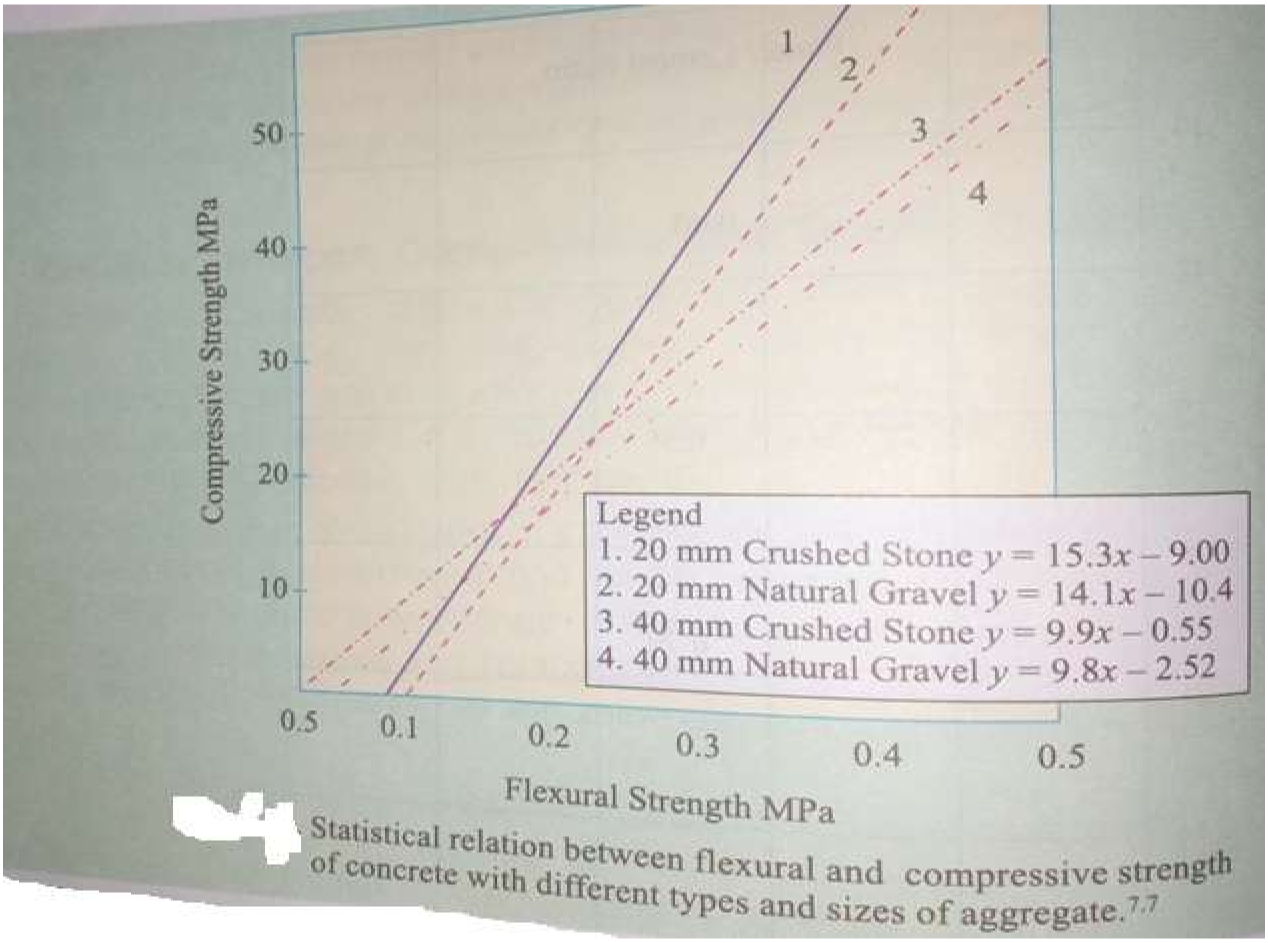


Fig 4.5 compressive strength V/s Flexural strength

Testing Of Hardened Concrete:

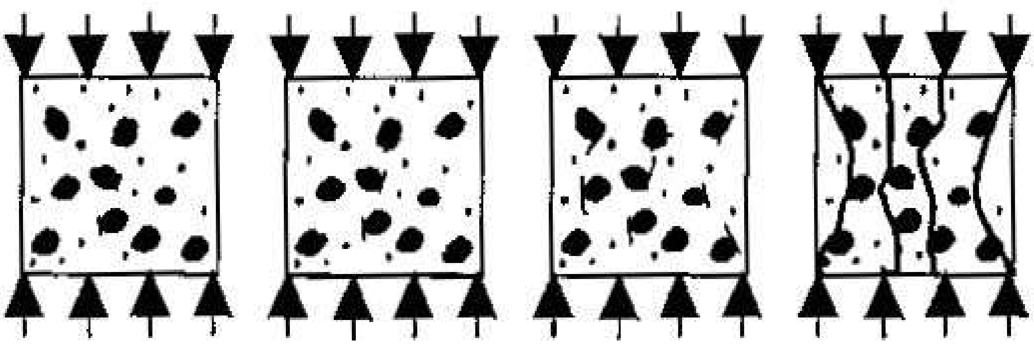
Compressive strength and corresponding tests

(a)Failure mechanism

a. At about 25-30% of the ultimate strength, random cracking (usually in transition zone around large aggregates) are observed

b. At about 50% of ultimate strength, cracks grow stably from transition zone into paste. Also, micro cracks start to develop in the paste.

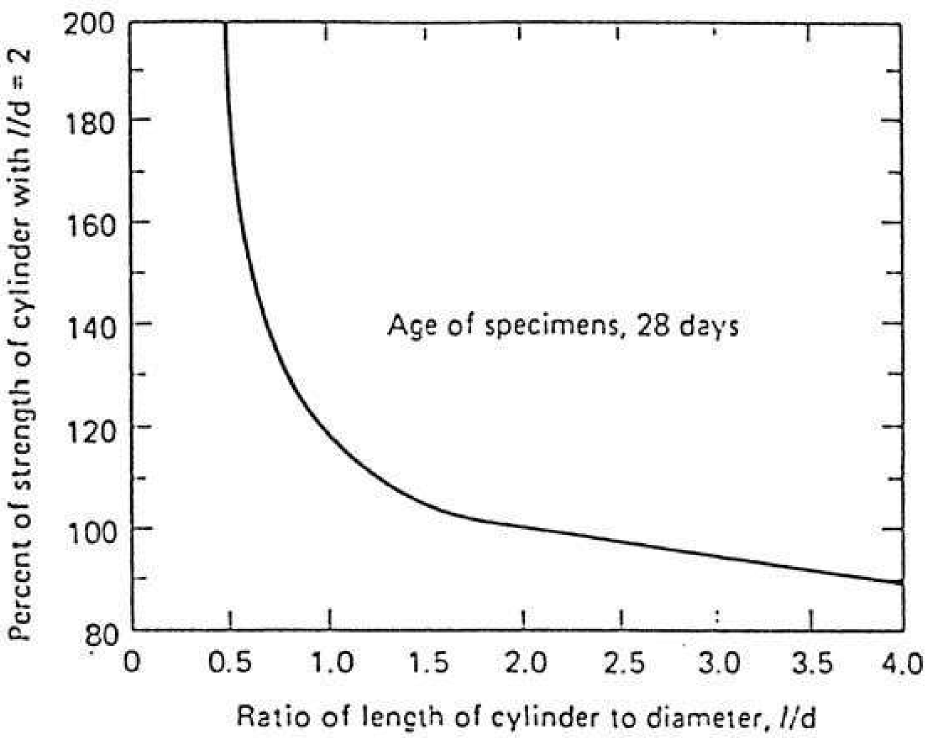
c. At about 75% of the ultimate strength, paste cracks and bond cracks start to join together, forming major cracks. The major cracks keep growing while smaller cracks tend to close.



d. At the ultimate load, failure occurs when the major cracks link up along the vertical direction and split the specimen

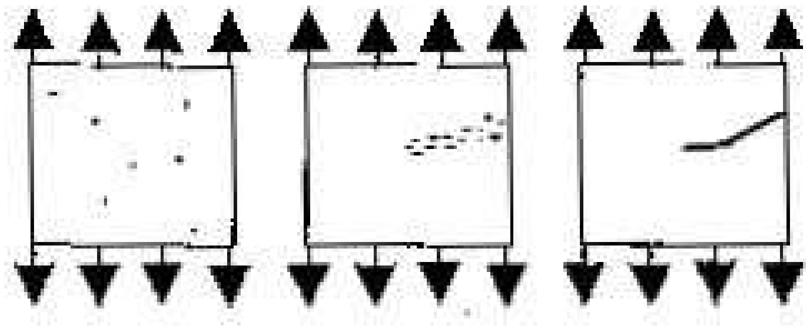
The development of the vertical cracks results in expansion of concrete in the lateral directions. If concrete is confined (i.e., it is not allow to expand freely in the lateral directions), growth of the vertical cracks will be resisted. The strength is hence increased, together with an increase in failure strain. In the design of concrete columns, steel stirrups are placed around the vertical reinforcing steel. They serve to prevent the lateral displacement of the interior concrete and hence increase the concrete strength. In composite construction (steel + reinforced concrete), steel tubes are often used to encase reinforced concrete columns. The tube is very effective in providing the confinement.

The above figure illustrates the case when the concrete member is under ideal uniaxial loading. In reality, when we are running a compressive test, friction exists at the top and bottom surfaces of a concrete specimen, to prevent the lateral movement of the specimen. As a result, confining stresses are generated around the two ends of the specimen. If the specimen has a low aspect ratio (in terms of height vs width), such as a cube (aspect ratio = 1.0), the confining stresses will increase the apparent strength of the material. For a cylinder with aspect ratio beyond 2.0, the confining effect is not too significant at the middle of the specimen (where failure occurs). The strength obtained from a cylinder is hence closer to the actual uniaxial strength of concrete. Note that in a cylinder test, the cracks propagate vertically in the middle of the specimen. When they get close to the ends, due to the confining stresses, they propagate in an inclined direction, leading to the formation of two cones at the ends.



Tensile strength and corresponding tests

(a) Failure mechanism



a. Random crack development (micro cracks usually form at transition zone)

b. Localization of micro cracks

c. Major crack propagation

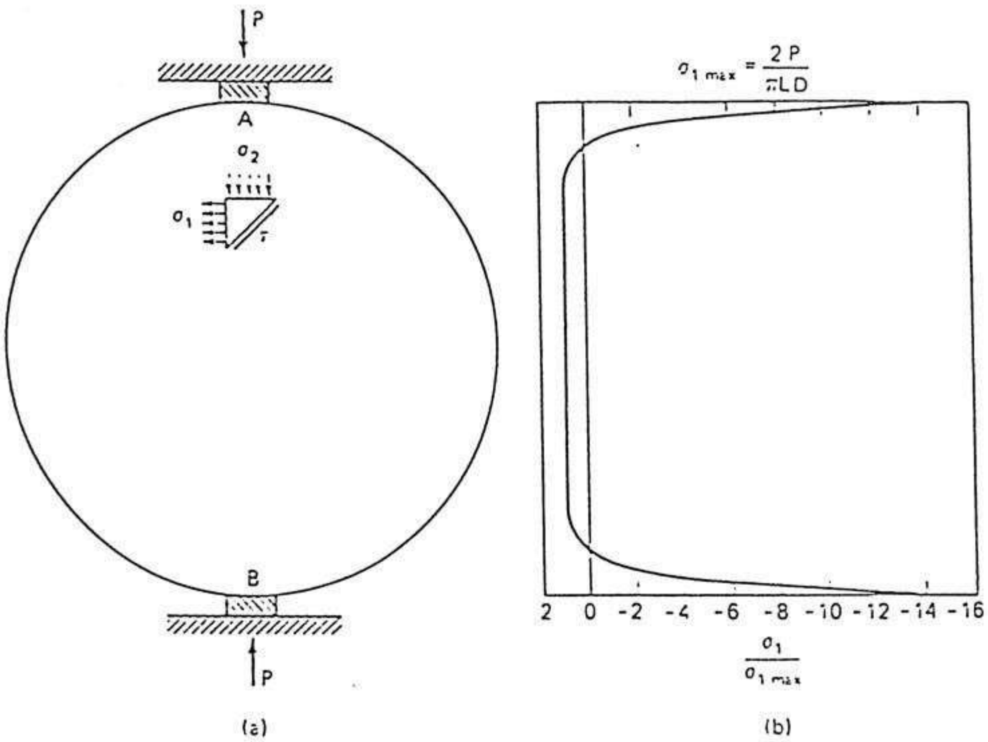
(b) Direct tension test methods

Direct tension tests of concrete are seldom carried out because it is very difficult to control. Also, perfect alignment is difficult to ensure and the specimen holding devices introduce secondary stress that cannot be ignored. In practice, it is common to carry out the splitting tensile test or flexural test.

(c) Indirect tension test (split cylinder test or Brazilian test) BS 1881: Part 117:1983.
Specimen 150 x 300 mm cylinder. Loading rate 0.02 to 0.04 MPa/s

ASTM C496-71:
Specimen 150 x 300 mm cylinder. Loading rate 0.011 to 0.023 MPa/s

The splitting test is carried out by applying compression loads along two axial lines that are diametrically opposite. This test is based on the following observation from elastic analysis. Under vertical loading acting on the two ends of the vertical diametrical line, uniform tension is introduced along the central part of the specimen.

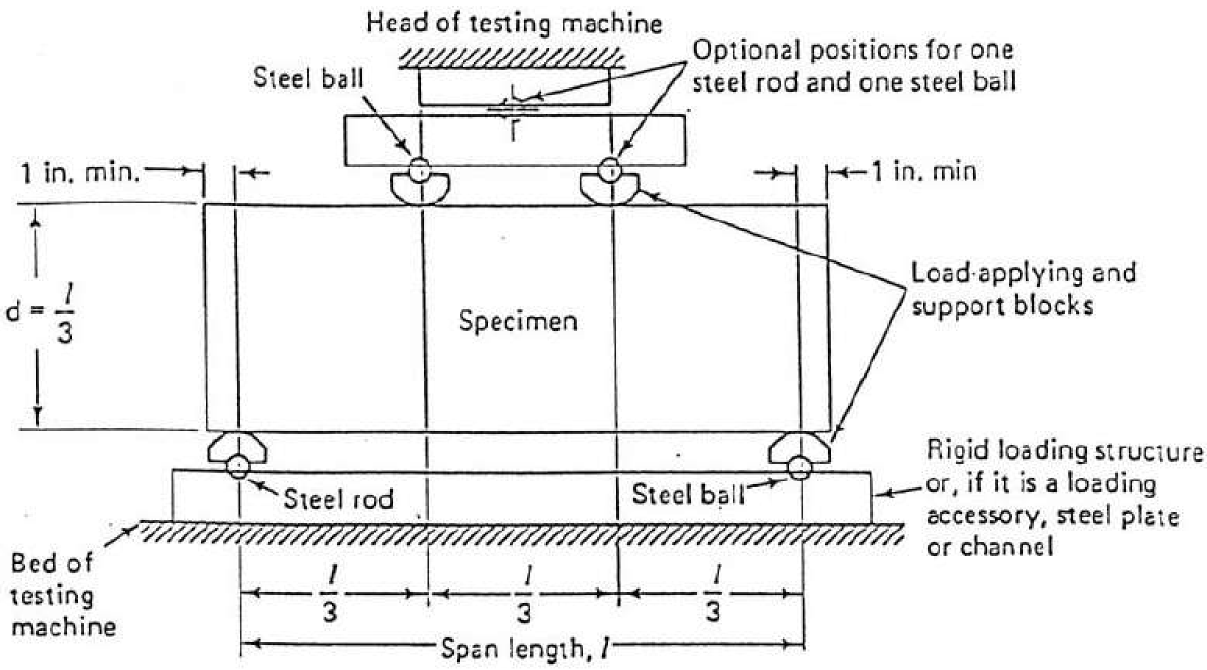


The splitting tensile strength can be obtained using the following formula:

$$f_{st} = \frac{2P}{\pi LD}$$

According to the comparison of test results on the same concrete, f_{st} is about 10-15% higher than direct tensile strength f_t .

Flexural strength and corresponding tests



BS 1881: Part 118: 1983. Flexural test. 150 x 150 x 750 mm or 100 x 100 x 500 (Max. size of aggregate is less than 25 mm). The arrangement for modulus of rupture is shown in the above figure.
From Mechanics of Materials, we know that the maximum tension stress should occur at the bottom of the constant moment region. The modulus of rapture can be calculated as:

$$f_{bt} = \frac{Pl}{bd^2}$$

This formula is for the case of fracture taking place within the middle one third of the beam. If fracture occurs outside of the middle one-third (constant moment zone), the modulus of rupture can be computed from the moment at the crack location according to ASTM standard, with the following formula.

$$f_{bt} = \frac{3Pa}{bd^2}$$

However, according to British Standards, once fracture occurs outside of the constant moment zone, the test result should be discarded.

Although the modulus of rupture is a kind of tensile strength, it is much higher than the results obtained from a direct tension test. This is because concrete can still carry stress after a crack is formed. The maximum load in a bending test does not correspond to the start of cracking, but correspond to a situation when the crack has propagated. The stress distribution along the vertical section through the crack is no longer varying in a linear manner. The above equations are therefore not exact.

It is important to notice that cracks form and propagate a lot easier in tension than in compression. The tensile strength is hence much lower than the compressive strength.

Non-Destructive Test

Non-destructive testing (NDT) methods are techniques used to obtain information about the properties or internal condition of an object without damaging the object. Non-destructive testing is a descriptive term used for the examination of materials and components in such way that allows materials to be examined without changing or destroying their usefulness. NDT is a quality assurance management tool which can give impressive results when used correctly. It requires an understanding of the various methods available, their capabilities and limitations, knowledge of the relevant standards and specifications for performing the tests. NDT techniques can be used to monitor the integrity of the item or structure throughout its design life.

The greatest disadvantage of the conventional methods of testing concrete lies in the fact that in-situ strength of the concrete can not be obtained without damaging the actual structure. Also the test specimens are destroyed, once the test is performed and subsequent testing of the same specimens is not possible. Thus the effect of prolonged curing, weathering action and other time dependent characteristics can not be correctly calculated. No matter how well a concrete mix is designed, there are variations in mixing conditions, amount of compaction or curing conditions at site which cause the variations in the final product. The variability between the batches of concrete of the same mix proportion is assessed by testing test specimens under load in the laboratory. Such tests enable the variability of constituents of the mix to be controlled, but they can not take into account the differences of compaction and actual curing conditions between the test specimens and the corresponding concrete in a structure. It is these differences, which are difficult to assess by conventional strength tests, Also, conventional method of testing is not sufficient to predict the performance of the structures under adverse conditions e.g. exposure to liquid, gas, and chemicals radiation, explosion, fire, extreme cold or hot weather, marine and chemical environment. All such severe exposure conditions may induce deterioration in concrete and impair the integrity, strength and stability of the structure. Thus, conventional strength test does not give idea about the durability and performance of the actual concrete in the structure. This gave the impetus to the development of non-destructive methods for testing structural concrete in-situ.

Thus, NDT methods are extremely valuable in assessing the condition of structures, such as bridges, buildings, elevated service reservoirs and highways etc. The principal objectives of the non-destructive testing of concrete in situ is to assess one or more of the following properties of structural concrete as below

- In situ strength properties
- Durability

- Density
- Moisture content
- Elastic properties
- Extent of visible cracks
- Thickness of structural members having only one face exposed
- Position and condition of steel reinforcement
- Concrete cover over the reinforcement.
- Reliable assessment of the integrity or detection of defects of concrete members even when they are accessible only from a single surface.

Non Destructive Tests for Concrete

- Surface Hardness Tests – Rebound Hammer Test
- Ultrasonic Pulse Velocity Test

CHMIDT'S REBOUND HAMMER TEST

OBJECTS

The rebound hammer method could be used for :

- Assessing the compressive strength of concrete with the help of suitable co-relations between rebound index and compressive strength
- Assessing the uniformity of the concrete
- Assessing the quality of concrete in relation to the standard requirements
- Assessing the quality of one element of concrete in relation to another.(1)

Principle of test: The test is based on the principle that the rebound of an elastic mass depends on the hardness of the surface upon which it impinges. When the plunger of the rebound hammer pressed against the surface of the concrete, the spring controlled mass rebounds and the extent of such rebound depend upon the surface hardness of concrete. The surface hardness and therefore the rebound is taken to be relation to the compressive strength of concrete. The rebound is read off along a graduated scale and is designated as the rebound number or rebound index.

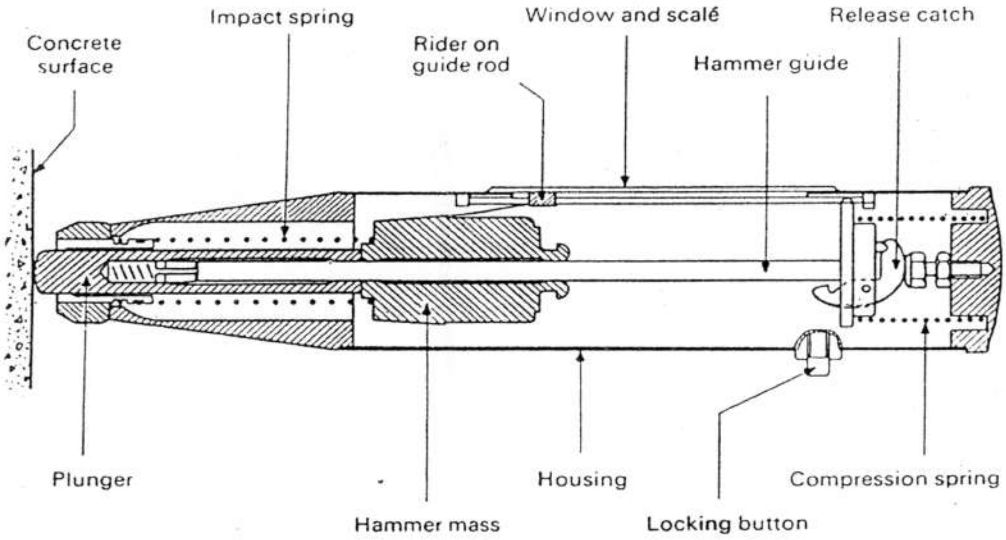
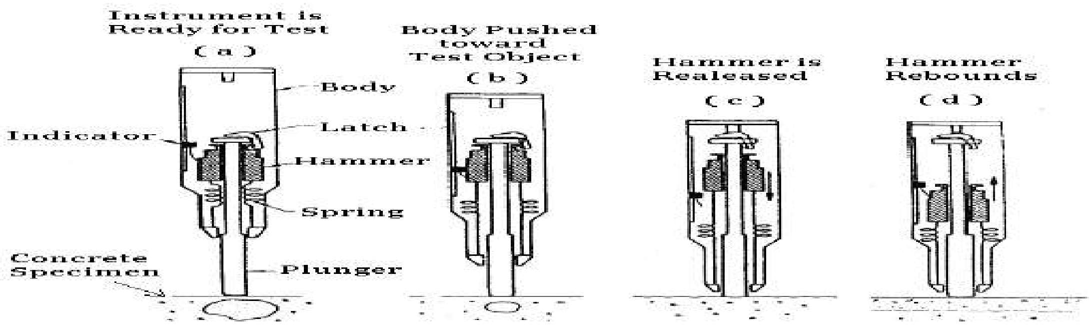


Fig.4.6 : Basic Features of Rebound Hammer

Working of rebound hammer: A schematic cut way view of schmidt rebound hammer is shown in fig. 1. The hammer weight about 1.8 kg., is suitable for use both in a laboratory and in the field. When the plunger of rebound hammer is pressed against the surface of concrete, a spring controlled mass rebounds and the extent of such rebound depends upon the surface hardness of concrete.

The rebound distance is measured on a graduated scale and is designated as rebound number. Basically, the rebound distance depends on the value of kinetic energy in the hammer, prior to impact with the shoulder of the plunger and how much of that energy is absorbed during impact. The energy absorbed by the concrete depends on the stress-strain relationship of concrete. Thus, a low strength low stiffness concrete will absorb more energy than high strength concrete and will give a lower rebound number.



Schematic Cross Section of Rebound Hammer Showing Principle of Operation

Fig.4.7: Schematic Cross Section of Rebound Hammer & Principle of Operation

Method of testing (operation)

1. To prepare the instrument for a test, release the plunger from its locked position by pushing the plunger against the concrete and slowly moving the body away from the concrete. This causes the plunger to extend from the body and the latch engages the hammer mass to the plunger rod.
2. Hold the plunger perpendicular to the concrete surface and slowly push the body towards the test object. (The surface must be smooth, clean and dry and should preferably be formed, but if trowelled surfaced are unavoidable, they should be rubbed smooth with the carborundum stone usually provided with the equipment. Loose material can be ground off, but areas which are rough from poor compaction, grout loss, spalling or tooling must be avoided, since the results will be unreliable).
3. As the body is pushed, the main spring connecting the hammer mass to the body is stretched. When the body is pushed to the limit, the latch is automatically released and the energy stored in the spring propels the hammer mass towards the plunger tip. The mass impacts the shoulder of the plunger rod and rebounds.
4. During rebound, the slide indicator travels with the hammer mass and records the rebound distance. A button on the side of the body is pushed to lock the plunger in the retracted position and the rebound number is read from the scale.

   The test can be conducted horizontally, vertically upward or downward or at any intermediate angle. Due to different effects of gravity on the rebound as the test angle is changed, the rebound number will be different for the same concrete. This will require separate calibration or correction charts, given by the manufacturer of the hammer.

Correlation procedure: Each hammer is provided with correlation curves developed by the manufacturer using standard cube specimens. However, the use of these curves is not recommended because material and testing conditions may not be similar to those in effect when the calibration of the instrument was performed. A typical correlation procedure is given as below:

1. Prepare a number of 150 mm cube specimens covering the strength range to be encountered on the job site. Use the same cement and aggregates as are to be used on the job. Cure the cubes under standard moist curing room conditions.
2. After capping, place the cubes in a compression testing machine under an initial load of approximately 15% of the ultimate load to restrain the specimen. Ensure that cubes are in saturated surface dry conditions.
3. Make 5 hammer rebound readings on each of four moulded faces without testing the same spot twice and minimum 20 mm gap from edges.
4. Average the readings and call this the rebound number for the cube under test.
5. Repeat this procedure for all the cubes.
6. Test the cubes to failure in compression and plot the rebound numbers against the compressive strength on a graph.
7. Fit a curve or a line by the method of least squares.

It is important to note that some of the curves deviate considerably from the curves supplied with the hammer.

Limitations: Although the rebound hammer provides a quick inexpensive means of checking the uniformity of concrete, it has serious limitations and these must be understood clearly for interpretation of test results.

Factors affecting rebound number

The results of Schmidt rebound hammer are significantly influenced by the following factors

(a) Smoothness of Test Surface
(b) Size, Shape and Rigidity of the Specimen
(c) Age of Test Specimen
(d) Moisture Condition
(e) Type of Coarse Aggregate
(f) Type of Cement
(g) Type of Mould

(h) Surface Carbonation

Influence of these factors has different magnitudes. Hammer orientation will also influence the measured values, although correction factors can be used to allow for this effect.

Precautions to be taken while using rebound hammer: The following precautionary measures are taken while using the rebound hammer which may give rise to minimize error

- The surface on which the hammer strikes should be smooth and uniform. Moulded faces in such cases may be preferred over the Trowelled faces.
- The test hammer should not be used within about 20 mm from the edge of the specimen.
- Rebound hammer should not be used over the same points more than once.
- The rebound test must be conducted closely placed to test points, on at least 10 to 12 locations while taking the average extremely high and low values of the index number should be neglected.

NON-DESTRUCTIVE TESTING OF CONCRETE BY ULTRASONIC PULSE VELOCITY METHOD

The ultrasonic pulse velocity method is used for non-destructive testing of plain, reinforced and prestressed concrete whether it is precast or cast in-situ

Objects: The main objects of the ultrasonic pulse velocity method are to establish

- The Homogeneity of the Concrete
- The Presence of Cracks, Voids and other Imperfections
- Changes in the Structure of the Concrete Caused by the Exposure Condition, Corrosion, Wear etc. which may occur with time,
- The Quality of the Concrete in Relation to the Specified Standard Requirements.
- The Quality of One Element of Concrete in Relation to the Another.
- The Values of the Dynamic Elastic Modulus of the Concrete.

Principle: This is one of the most commonly used method in which the ultrasonic pulses generated by electro-acoustical transducer are transmitted through the concrete. In solids, the particles can oscillate along the direction of sound propagation as longitudinal waves or the oscillations can be perpendicular to the direction of sound waves as transverse waves. When the pulse is induced into the concrete from a transducer, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves is developed which includes longitudinal (Compressional), shear (Transverse) and surface (Rayleigh) waves. This transducers convert electrical signals into mechanical vibrations (transmit mode) and mechanical vibration into electrical signals (receive mode). The travel time is measured with an accuracy of +/- 0.1 microseconds. Transducers with natural frequencies between 20 kHz and 200 kHz are available, but 50 kHz to 100 kHz transducers are common.

The receiving transducer detects the onset of the longitudinal waves which is the fastest wave. Because the velocity of the pulses is almost independent of the geometry of the material through which they pass and depends only on its elastic property. Under certain specified conditions, the velocity and strength of concrete are directly related. The common factor is the density of concrete; a change in the density results in a change in a pulse velocity, likewise for a same mix with change in density, the strength of concrete changes. Thus lowering of the density caused by increase in water-cement ratio decreases both the compressive strength of concrete as well as the velocity of a pulse transmitted through it.

Pulse Velocity method is a convenient technique for investigating structural concrete. The underlying principle of assessing the quality of concrete is that comparative higher velocities are obtained when the quality of concrete in terms of density, homogeneity and uniformity is good. In case poorer quality of concrete, lower velocities are obtained. If there is a crack, void or flaw inside the concrete which comes in the way of transmission of the pulses, the pulse strength is attenuated and it passes around the discontinuity, thereby making path length longer. Consequently, lower velocities are obtained. The actual pulse velocity obtained depends primarily upon the material and the mix proportion of the concrete. Density and modulus of elasticity of aggregate also significantly affect the pulse velocity.

Transducers: Piezoelectric and magnetostrictive types of transducers are available in the range of 20 kHz to 150 kHz of natural frequency. Generally, high frequency transducers are preferable for short path length and low frequency transducers for long path lengths. Transducers with a frequency of 50 to 60 kHz are useful for most all-round applications.

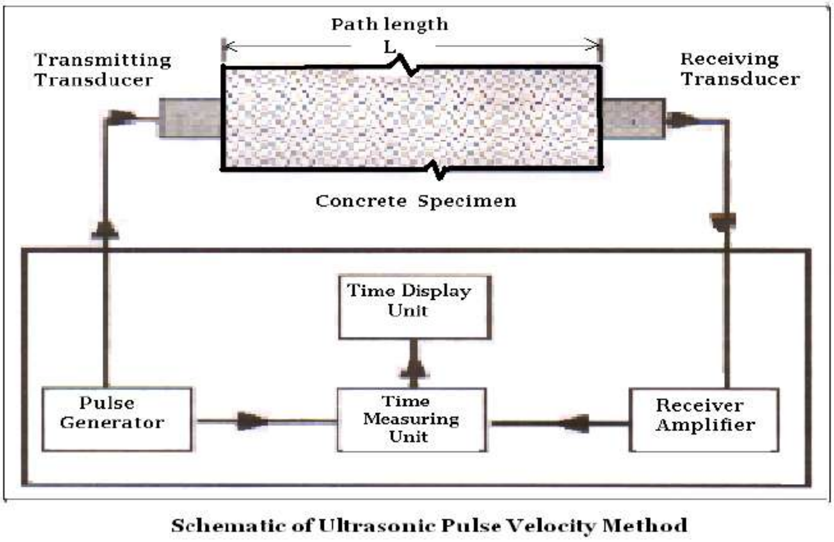


Fig. 4.8: Schematic Diagram of Ultrasonic Pulse Velocity Method

There are three possible ways of measuring pulse velocity through concrete :

a. **Direct Transmission (Cross Probing) through Concrete** : In this method transducers are held on opposite face of the concrete specimen under test as shown in fig. The method is most commonly used and is to be preferred to the other two methods because this results in maximum sensitivity and provides a well defined path length.

b. **Semi-direct Transmission through Concrete :** Sometimes one of the face of the concrete specimen under test is not accessible, in that case we have to apply semi-direct method as shown in fig. In this method, the sensitivity will be smaller than cross probing and the path length is not clearly defined.

c. **Indirect Transmission (Surface Probing) through Concrete :** This method of pulse transmission is used when only one face of concrete is accessible. Surface probing is the least satisfactory of the three methods because the pulse velocity measurements indicate the quality of concrete only near the surface and do not give information about deeper layers of concrete. The weaker concrete that may be below a strong surface can not be detected. Also in this method path length is less well defined. Surface probing in general gives lower pulse velocity than in the case of cross probing and depending on number of parameters.

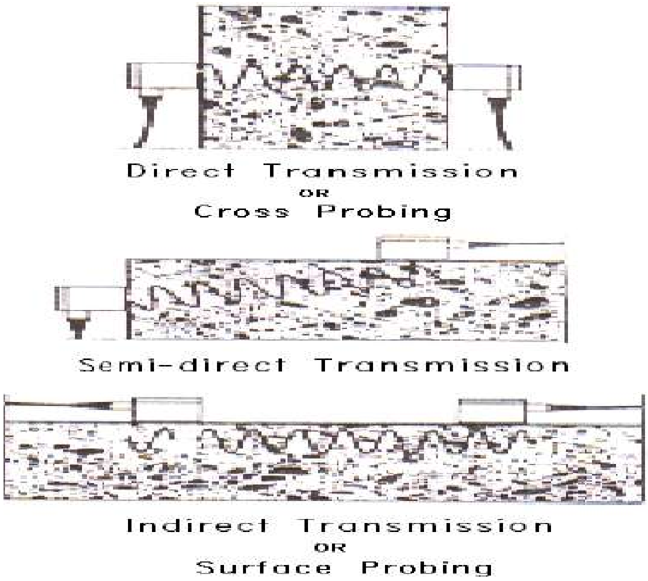


Fig. 4.9: Different Methods of Propagating Ultrasonic Pulses through Concrete

Table 2 : Velocity Criteria For Concrete Quality Grading

As per Table 2 of IS 13311 (Part 1) : 1992

Sr. No.	Pulse Velocity by Cross Probing (km/sec)	Concrete Quality Grading
1.	Above 4.5	Excellent
2.	3.5 to 4.5	Good
3.	3.0 to 3.5	Medium
4.	Below 3.0	Doubtful

Note : In case of doubtful quality of concrete, it may be necessary to carry out further tests.

Combined methods: There are different non-destructive testing methods which can be broadly classified as those which measure the overall quality of the concrete, dynamic or vibration methods like resonance frequency and ultrasonic pulse velocity tests and those which involve measurement of parameters like surface hardness, rebound, penetration, pull-out strength etc. are believed to be indirectly related to the compressive strength of concrete. In addition, radiographic, radiometric, nuclear, magnetic and electrical methods are also available. Since such non-destructive tests are at best indirect methods of monitoring the particulars, characteristics of concrete. The measurements are influenced by materials, concrete mix proportions and environmental factors. When the data of the materials and mix proportions used in the construction are not available, as is often the case. In view of the limitation of the methods for the predicting the strength of concrete in the structure, IS 13311 (Part 1) : 1992 Code has suggested to use combined method of ultrasonic pulse velocity and rebound hammer methods to alleviate the errors arising out of influence of materials, concrete mix proportions and environmental parameters on the respective measurement.

The use of more than one methods are capable of providing useful information and statically improved accuracy for estimation of in situ strength of concrete.

Combination of ultrasonic pulse velocity method and Schmidt rebound hammer may result much better estimation of strength of concrete because the influence of certain factors in the composition of the concrete and its curing are minimized.

FACTORS AFFECTING THE MEASUREMENTS OF PULSE VELOCITY

- Smoothness of Concrete Surface under Test
- Moisture Condition of Concrete
- Influence of Path Length on Pulse Velocity
- Lateral Dimensions.
- Temperature of Concrete
- Effect of Reinforcing BarsInfluence of stress

Assignment-Cum-Tutorial Questions

A. Questions testing the remembering / understanding level of students

I) Objective Questions

1. Curing

   A. reduces the shrinkage of concrete

   B. preserves the properties of concrete

   C. prevents the loss of water by evaporation

   D. All of the above.

2. The process of proper and accurate measurement of concrete ingredients for uniformity of proportion, is known

   A. Grading

   B. Curing

   C. Mixing

   D. Batching

   E. none of these.

3. The preliminary test is repeated if the difference of compressive strength of three test specimens, exceeds

   A. 5 kg/cm^2

   B. 8 kg/cm^2

   C. 10 kg/cm^2

   D. 12 kg/cm^2

   E. 15 kg/cm^2

4. Hardening of cement occurs at

   A) Slow rate during the first few days and afterwards it continues to increase at a rapid rate

   B) Rapid rate during the first few days and afterwards it continues to increase

at a decreased rate
C) None of these.
D) Uniform rate throughout its age

5. Specified compressive strength of concrete is obtained from cube tests at the end of

A) 21 days
B) 28 days.
C) 14 days
D) 7 days

6. Comp. Strength test can be done by using_______________
7. What are the standard units of tensile strength_____________
8. The strength of concrete is influenced by

a) Size of specimen (b) moisture conditions
(c) Type and rate of loading (d) all of the above

II) Descriptive Questions

1. What is water cement ratio?
2. Define the gel/space ratio?
3. What is water cement ratio and Abram's law?
4. What is NDT?
5. What is Abram's law?
6. What is curing of concrete?
7. What is maturity concept?
8. What are the different NDT tests?
9. What is the relation between compression strength and tensile strength?

B. Questions testing the ability of students in applying the concepts.

I) Multiple Choice Questions:

1. Curing a concrete for long period ensures better

A. volume stability

B. Strength

C. water resistance

D. water tightness and durability

E. All the above.

2. The approximate value of the ratio between direct tensile strength and flexural strength is

a) 0.33 b) 0.5 c) 0.75 d) 1.0

3. Strength of concrete increases with

a) Increase in w/c ratio

b) Increase in fineness of cement

c) Decrease in curing time

d) Decrease in size of aggregate

4. The comp. Strength of 100mm cube as compared to 150mm cube is always

a) less

b) More

c) Equal

d) None of the above

5. The strength of concrete after one year as compared to 28 days strength is about

a) 10 to 15% more

b) 15 to 20% more

c) 20 to 25% more

d) 25 to 50% more

6. Modulus of rupture of concrete is a measure of

a) Flexural tensile strength

b) Direct tensile strength

c) Compressive strength

d) Split tensile strength

II) Descriptive Questions / PROBLEMS

1. What the different tests are of hardened of concrete? Explain in detail.

2. Write the factors affecting the strength of concrete.

3. Write about gel space ratio and gain of strength of concrete with age?

4. Write about the maturity concept of concrete.

5. Discuss the Abram's water/cement ration law and its significance. How strength of concrete is estimated by w/c ratio law.

6. Explain with neat diagram non-destructive testing of concrete using Rebound Hammer Method.

7. Write the testing procedure of determination of flexural strength.

8. Write a brief note on split tensile strength of Concrete.

9. Write a brief note on Flexure strength of Concrete.

10. The strength of sample of fully matured concrete is found to be 40.00 Mpa find the strength of identical concrete at the age of 7 days when cured at an average temparature during day time at 20^0 C, and night time at 10^0 C.

C. Questions testing the analyzing /evaluating ability of students

1. Discuss the relation between flexural strength and comp. Strength.

2. Explain the role of aggregate size on strength properties on concrete.

3. Discuss the suitability's of NDT tests for various constructions.

4. How do you assess the strength of existing concrete structure by adopting suitable test without destructing the structure.

D. GATE/ Competitive oriented bits

1. The strength of concrete mainly depends upon
a) Quality of F.A. (b) Quality of C.A. (c) Fineness of cement d) w/c ratio
2. The concrete may attain its 95% compressive strength after
a) 7 days (b) 14 days (c) 28 days (d) 1 year (e) 3 years
3. According to Indian standard specifications, the maximum compressive strength of normal strength concrete can be
a) 5 MPa (b) 12.5 MPa (c) 15 MPa (d) 20 MPa (e) 40 MPa
4. The unit weight of reinforced concrete is generally taken as
a) 24 KN/m^3 (b) 22 KN/m^3 (c) 20 KN/m^3 (d) 25 KN/m^3

UNIT – V

Concrete Technology

Objective: To know the creep, elasticity and shrinkage of concrete.

Syllabus: Modulus Of Elasticity-Dynamic Modulus Of Elasticity-Poisson's Ratio-Creep Of Concrete-Factors Influencing Creep-Relation Between Creep & Time-Nature Of Creep-Effects Of Creep-Shrinkage-Types Of Shrinkage-Types Of Shrinkage. Factors Contributing To Cracks In Concrete, Sulphate Attack And Methods Of Controlling Sulphate Attack, Chloride Attack, Corrosion Of Steel And Its Control.

Learning outcomes:

Students will be able to

(i) Narrate the elastic properties of concrete
(ii) Explain the properties of creep and shrinkage.
(iii) Adopt suitable controlling methods of corrosion of steel.

INTRODUCTION

Concrete has relatively high compressive strength, but significantly lower tensile strength, and as such is usually reinforced with materials that are strong in tension (often steel). The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develop. Concrete has a very low coefficient of thermal expansion, and as it matures concrete shrinks. All concrete structures will crack to some extent, due to shrinkage and tension. Concrete which is subjected to long-duration forces is prone to creep

MODULUS OF ELASTICITY:

Stress and strain relationship of aggregate is straight line. Similarly, stress strain relationship of cement paste straight line. But the stress strain relationship of concrete which is combination of aggregate and paste together shows a curved relationship. Perhaps this is due to the development of micro cracks at the interface of the aggregate and paste. Because of the failure of bond at the interface increases at a faster rate than that of the applied stress, the stress strain curve continuous to bend faster than increase of stress. Fig shows the strain strain relationship for cement paste, aggregate and concrete.

Concrete exhibits very peculiar rheological behavior because of its being a heterogeneous, multi phase material whose behavior is influenced by the elastic properties and morphology of gel structures .The modulus of elasticity concrete being so important and at the same time so complicated.

The modulus of elasticity can also be determined by subjecting a concrete beam to bending and then using the formula for deflection and substituting other parameters. The modulus of elasticity so found out from actual loading is called static modulus of elasticity.

Modulus of elasticity of concrete increases approximately with the square root of the strength. The IS 456 of 2000 gives the modulus of elasticity as $E_c = 5000$

Where E_c is the short term static modulus of elasticity in N/mm^2 .

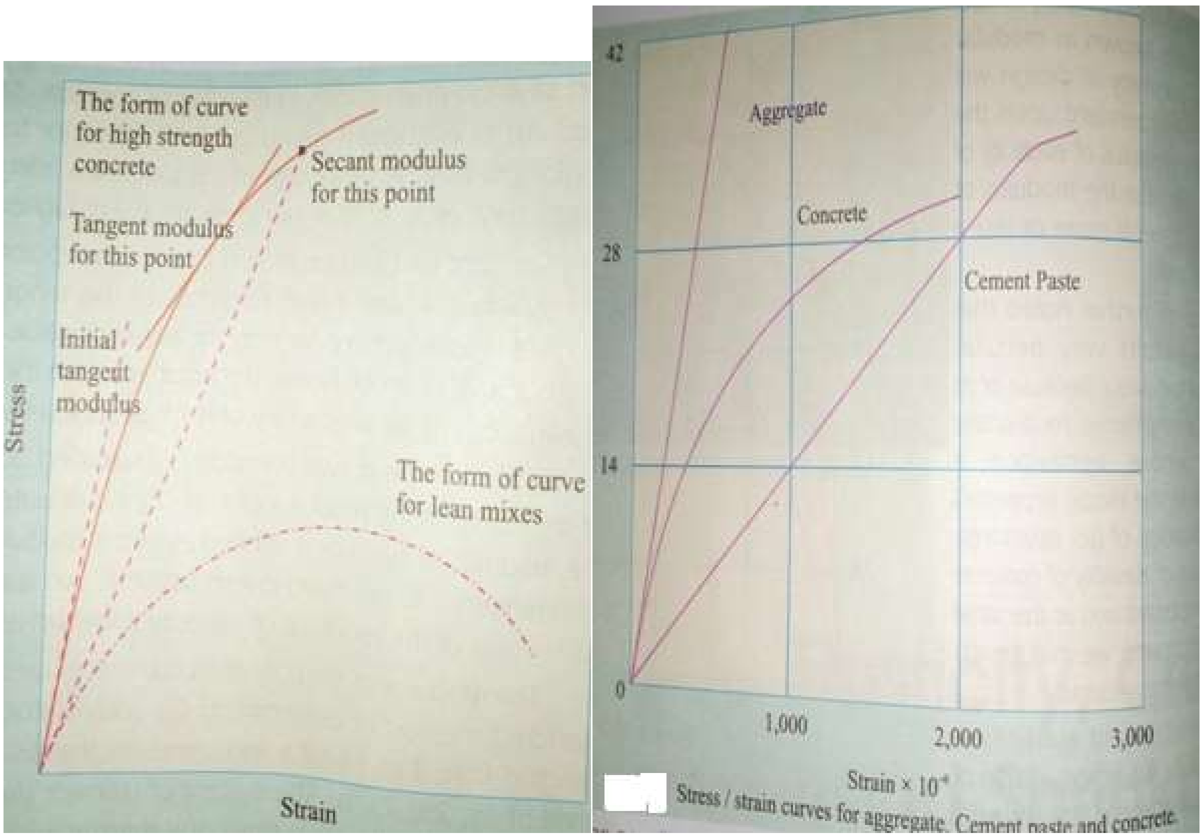


Fig 5.1 different modulus of elasticity

Factors affecting on modulus of elasticity

Some of the factors affecting on modulus of elasticity

Strength of concrete is one of the important factor affecting the modulus of elasticity.

Wetness of concrete is also affecting the modulus of elasticity. Wet concrete will show higher modulus of higher modulus of elasticity than dry concrete.

Moisture content on concrete is affecting the modulus of elasticity.

The quantity and quality of aggregates will have significant affect on the modulus of elasticity. Modulus of elasticity of aggregates influences the modulus elasticity of concrete.

If the modulus of elasticity of aggregates is E_a and that of the paste E_p then the modulus of elasticity of concrete E is found out to be

Where V_p and V_a are volume of paste and aggregate respectively in the concrete.

DYNAMIC MODULUS OF ELASTICITY:

Stress strain relationship of concrete exhibits complexity particularly due to the peculiar behavior of gel structure and the manner in which the water is held in hardened concrete. The value of E is found out by actual loading of concrete i.e., the static modulus of elasticity does not truly represent the elastic behavior of concrete due to the phenomenon of creep. The elastic modulus of elasticity will get affected more seriously at higher stress when the effect of creep is more pronounced.

The modulus of elasticity can be determined by subjecting the concrete member to longitudinal vibration at their natural frequency. This method involves the determination of either resonant frequency through a specimen of concrete or pulse velocity travelling through the concrete. By making use of the above parameters modulus of elasticity can be calculated from the following relationship

$E_d = Kn^2 L^2 ϸ$

E_d = dynamic modulus of elasticity

K = constant

N= resonant frequency

L= length of specimen in mm

Ƥ = density of concrete kg/m^3

Then

$E_d = 4 X 10^{-15} n^2 L^2 ϸ$ GPa

The value of dynamic modulus of elasticity computed from ultrasonic pulse velocity method is somewhat higher than those determined by static method. This is because the modulus of elasticity as determined by dynamic modulus is unaffected by creep. The creep also does also does not significantly effect the initial tangent modulus in the static method. Therefore, the value of dynamic modulus and the value of initial tangent modulus are found to be more or less agree with each other. Approximate relationship between the two modulai expressed in GN/ m^2 is given by

$$E_c = 1.25\ E_d - 19$$

Where E_c and E_d are the static and dynamic modulus of elasticity.

Poisson's ratio:

Sometimes in design and analysis of structures, the knowledge of poisons ratio is required. Poisson's ratio is the ratio is the ratio between lateral strain to the longitudinal strain. it is generally denoted by **µ**. for normal concrete the value of poisson's ratio lies in the range of 0.15 to 0.20 when actually determined from strain measurements.

as an alternative method, poisson's ratio can be determined from ultrasonic pulse velocity method and by finding out the fundamental resonant frequency of longitudinal vibration of concrete beam. the poisson's ratio **µ** can be calculated from the following equation.

Where V is the pulse velocity (mm/s)

n is the resonant frequency(Hz), the value ranges from 0.2 to 0.24

Dynamic modulus of elasticity can also be found out from the following equation

V is the pulse velocity

p is the density

µ is the Poisson's ratio

Creep: Creep is defined as the time-dependent deformation under a constant load. Water movement under stress is a major mechanism leading to creeping of concrete. As a result, factors affecting shrinkage also affect creep in a similar way. Besides moisture movement, there is evidence that creep may also be due to time-dependent formation and propagation of micro cracks, as well as micro structural adjustment under high stresses (where stress concentration exists). These mechanisms, together with water loss from the gel interlayer, lead to irreversible creep. Creeping develops rapidly at the beginning and gradually decreases with time. Approximately 75% of ultimate creep occurs during the first year. The ultimate creep strain (after 20 years) can be 3-6 times the elastic strain.

Creep can influence reinforced concrete in the following aspects.

i) Due to the delayed effects of creep, the long-term deflection of a beam can be 2-3 times larger than the initial deflection.

ii) Creeping results in the reduction of stress in pre-stressed concrete which can lead to increased cracking and deflection under service load.

iii) In a R.C column supporting a constant load, creep can cause the initial stress in the steel to double or triple with time because steel is non-creeping and thus take over the force reduced in concrete due to creep. Creep is significantly influenced by the stress level. For concrete stress less than 50% of its strength, creep is linear with stress.

Factors affecting Creep of concrete

a) w/c ratio: The higher the w/c ratio, the higher is the creep.

b) Aggregate stiffness (elastic modulus): The stiffer the aggregate, the smaller the creep.

c) Aggregate fraction: higher aggregate fraction leads to reduced creep.

d) Theoretical thickness: The theoretical thickness is defined as the ratio of section area to the semi perimeter in contact with the atmosphere. Higher the theoretical thickness, smaller the creep and shrinkage.

e) Temperature: with increasing temperature, both the rate of creep and the ultimate creep increase. This is due to the increase in diffusion rate with temperature, as well as the removal of more water at a higher temperature.

f) Humidity: with higher humidity in the air, there is less exchange of moisture between the concrete and the surrounding environment. The amount of creep is hence reduced.

g) Age of concrete at loading: The creep strain at a given time after the application of loading is lower if loading is applied to concrete at a higher age. For example, if the same loading is applied to 14 day and 56 day concrete (of the same mix), and creep strain is measured at 28 and 70 days respectively (i.e., 14 days after load application), the 56 day concrete is found to creep less. This is because the hydration reaction has progressed to a greater extent in the 56 day concrete. With less capillary pores to hold water, creep is reduced.

Relation between creep and time:

If a member is loaded and if this is sustained for some length of time and then removed, the specimen instantaneously recovers the elastic strain. The magnitude of instantaneous recovery of the elastic strain is something less than that of the magnitude of the elastic strain on loading. With time, certain amount of creep strain is also recovered. It is estimated that about 15 percent of creep is only recoverable. The member will have certain amount of residual strain. This shows that the creep is not a simply reversible phenomenon. fig shows the pattern of strain of a loaded specimen and the recovery of strain on unloading after sometime.

Measurement of creep:

Creep is usually determined by measuring the change with time in the strain of specimen subjected to constant stress and stored under appropriate condition. A typical testing device is shown in fig. the spring ensures that the load is sensibly constant in spite of the fact that the specimen contracts with time. Under such conditions, creep continues for a very long time, but the rate of creep decreases with time.

It is generally assumed that the creep continues to assume a limiting value after an infinite time under load. It is estimated that 26% of the 20 year creep occurs in 2 weeks. 55% of 20 year creep occurs in 3 months and 76% of 20 year creep occurs in one year.

If creep one year is taken as unity, then the average value of creep at later ages are:

1.14 After 2 years

1.20 After 5 years

1.26 After 10 years

1.33 After 20 years and

1.36 After 30 years

$$c=$$

c= specific creep

t= time under load

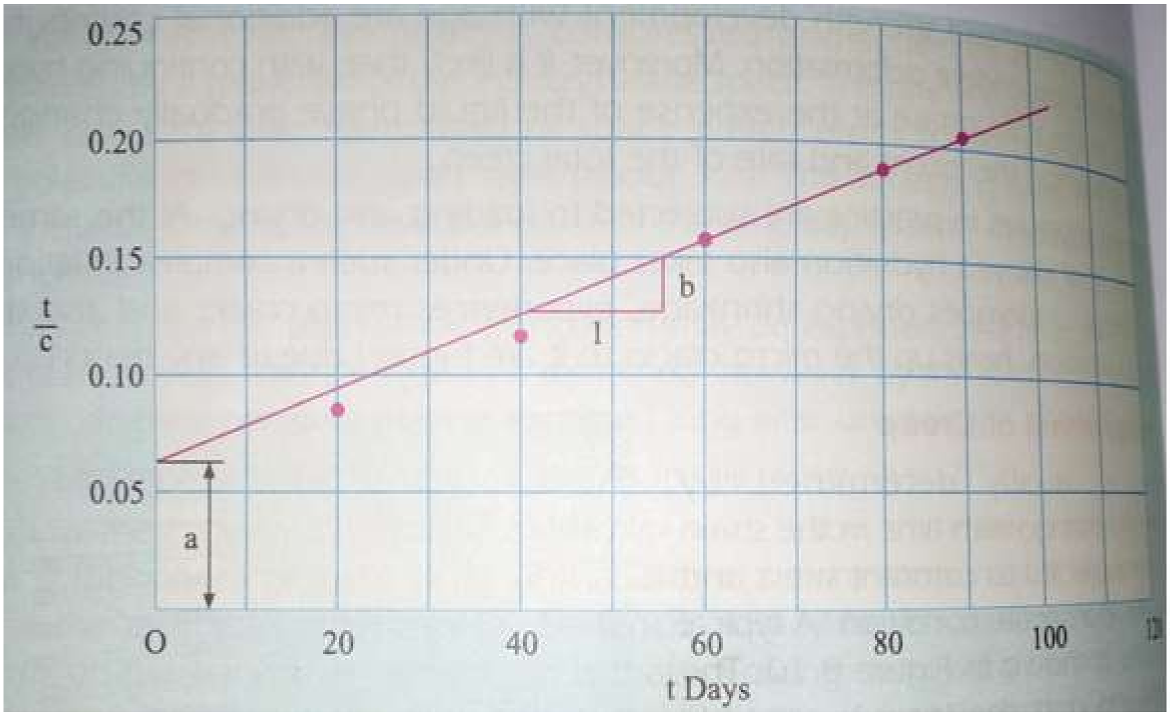


Fig.5.2. Creep constants

Where ‘a’ and ‘b’ are constants. if a graph is drawn with ‘t’ in the X-axis and t/c in the Y-axis. It shows a straight line of slope b and the intercept on the t/c is equal to a

then the constant can be easily found out. refer the fig 8.12. The ultimate creep at infinite time will be 1/b from the above expression. It is interesting to observe that when t=a/b.

c=b. i.e., one half of the ultimate creep is realized at time t=a/b

Effects of creep:

The magnitude of creep is dependent on many factors, the main factors being time and level of stress. In reinforced concrete beams, creep increases the deflection with time and may be a critical consideration in design.

In reinforced concrete columns, creep property of concrete is useful. Under load immediately elastic deformation takes place. Concrete creeps and deforms. It cannot deform independent of steel reinforcement. There will be gradual transfer of stress from concrete to steel. The extra load in the steel is required to be shared by concrete and this situation results in employment and development of full strength of both the materials. However, in eccentrically loaded columns, creep increases the deflection and can load to buckling.

In case of statically indeterminate structures and column and beam junctions creep may relieve the stress concentration induced by shrinkage, temperature changes or movement of support. Creep property of concrete will be useful in all concrete structures to reduce the internal stress due to non-uniform load or restrained shrinkage.

Shrinkage in Concrete

Concrete is subjected to changes in volume either autogenous or induced. Volume change is one of the most detrimental properties of concrete, which affects the long-term strength and durability. To the practical engineer, the aspect of volume change in concrete is important from the point of view that it causes unsightly cracks in concrete.

We have discussed elsewhere the effect of volume change due to thermal properties of aggregate and concrete, due to alkali/aggregate reaction, due to sulphate action etc. Presently we shall discuss the volume change on account of inherent properties of concrete **"shrinkage".**

One of the most objectionable defects in concrete is the presence of cracks, particularly in floors and pavements. One of the important factors that contribute to the cracks in floors and pavements is that due to shrinkage. It is difficult to make concrete which does not shrink and crack. It is only a question of magnitude.

Now the question is how to reduce the shrinkage and shrinkage cracks in concrete structures.
The term shrinkage is loosely used to describe the various aspects of volume changes in concrete due to loss of moisture at different stages due to different reasons.

Types of Shrinkage in Concrete

To understand this aspect more closely, shrinkage can be classified in the following way:

(a) Plastic Shrinkage

(b) Drying Shrinkage

(c) Autogeneous Shrinkage

(d) Carbonation Shrinkage

The Types of shrinkage are explained as below:

a. Plastic Shrinkage

Shrinkage of this type manifests itself soon after the concrete is placed in the forms while the concrete is still in the plastic state. Loss of water by evaporation from the surface of concrete or by the absorption by aggregate or sub grade, is believed to be the reasons of plastic shrinkage. The loss of water results in the reduction of volume. The aggregate particles or the reinforcement comes in the way of subsidence due to which cracks may appear at the surface or internally around the aggregate or reinforcement.
In case of floors and pavements where the surface area exposed to drying is large as compared to depth, when this large surface is exposed to hot sun and drying wind, the surface of concrete dries very fast which results in plastic shrinkage. Sometimes even if the concrete is not subjected to severe drying, but poorly made with a high water/cement ratio, large quantity of water bleeds and accumulates at the surface. When this water at the surface dries out, the surface concrete collapses causing cracks.

Plastic concrete is sometimes subjected to unintended vibration or yielding of formwork support which again causes plastic shrinkage cracks as the concrete at this stage has not developed enough strength. From the above it can be inferred that high water/cement ratio, badly proportioned concrete, rapid drying, greater bleeding, unintended vibration etc., are some of the reasons for plastic shrinkage. It can also be further added that richer concrete undergoes greater plastic shrinkage.

Plastic shrinkage can be reduced mainly by preventing the rapid loss of water from surface. This can be done by covering the surface with polyethylene sheeting immediately on finishing operation; by fog spray that keeps the surface moist; or by working at night. Use of small quantity of aluminum powder is also suggested to offset the effect of plastic shrinkage.

Similarly, expansive cement or shrinkage compensating cement also can be used for controlling the shrinkage during the setting of concrete.

b. Drying Shrinkage

Just as the hydration of cement is an everlasting process, the drying shrinkage is also an ever lasting process when concrete is subjected to drying conditions. The drying shrinkage of concrete is analogous to the mechanism of drying of timber specimen. The loss of free water contained in hardened concrete, does not result in any appreciable dimension change. It is the loss of water held in gel pores that causes the change in the volume. Under drying conditions, the gel water is lost progressively over a long time, as long as the concrete is kept in drying conditions. Cement paste shrinks more than mortar and mortar shrinks more than concrete. Concrete made with smaller size aggregate shrinks more than concrete made with bigger size aggregate. The magnitude of drying shrinkage is also a function of the fineness of gel. **The finer the gel the more is the shrinkage.**

c. Autogeneous Shrinkage

In a conservative system i.e. where no moisture movement to or from the paste is permitted, when temperature is constant some shrinkage may occur. The shrinkage of such a conservative system is known as autogeneous shrinkage. Autogeneous shrinkage is of minor importance and is not applicable in practice to many situations except that of mass of concrete in the interior of a concrete dam.

d. Carbonation Shrinkage

Carbon dioxide present in the atmosphere reacts in the presence of water with hydrated cement.

Calcium hydroxide [Ca(OH)2] gets converted to calcium carbonate and also some other cement compounds are decomposed. Such a complete decomposition of calcium compound in hydrated cement is chemically possible even at the low pressure of carbon dioxide in normal atmosphere. Carbonation penetrates beyond the exposed surface of concrete very slowly.

The rate of penetration of carbon dioxide depends also on the moisture content of the concrete and the relative humidity of the ambient medium. **Carbonation is accompanied by an increase in weight of the concrete and by shrinkage.**

Carbonation shrinkage is probably caused by the dissolution of crystals of calcium hydroxide and deposition of calcium carbonate in its place. As the new product is less in volume than the product replaced, shrinkage takes place.

Carbonation of concrete also results in increased strength and reduced permeability, possibly because water released by carbonation promotes the process of hydration and also calcium carbonate reduces the voids within the cement paste. As the magnitude of carbonation shrinkage is very small when compared to long term drying shrinkage, this aspect is not of much significance shrinkage.

Factors Affecting Shrinkage

One of the most important factors that affects shrinkage is the drying condition or in other words, the relative humidity of the atmosphere at which the concrete specimen is kept. If the concrete is placed in 100 per cent relative humidity for any length of time, there will not be any shrinkage; instead there will be a slight swelling. The typical relationship between shrinkage and time for which concrete is stored at different relative humidities is shown in Figure. The graph shows that the magnitude of shrinkage increases with time and also with the reduction of relative humidity.

The rate of shrinkage decreases rapidly with time. It is observed that 14 to 34 per cent of the 20 year shrinkage occurs in 2 weeks, 40 to 80 per cent of the 20 year shrinkage occurs in 3 months and 66 to 85 per cent of the 20 year shrinkage occurs in one year. Another important factor which influences the magnitude of shrinkage is water/cement ratio of the concrete. The richness of the concrete also has a significant influence on shrinkage. Aggregate plays an important role in the shrinkage properties of concrete. The quantum of an aggregate, its size, and its modulus of elasticity influence the magnitude of drying shrinkage.

Harder aggregate with higher modulus of elasticity like quartz shrinks much less than softer aggregates such as sandstone.
Moisture Movement Concrete shrinks when allowed to dry in air at a lower relative humidity and it swells when kept at 100 per cent relative humidity or when placed in water.

Just as drying shrinkage is an ever continuing process, swelling, when continuously placed in water is also an ever continuing process. If a concrete sample subjected to drying condition, at some stage, is subjected to wetting condition, it starts swelling. It is interesting to note that all the initial drying shrinkage is not recovered even after prolonged storage in water which shows that the phenomenon of drying shrinkage is not a fully reversible one.

Just as the **drying shrinkage** is due to loss of adsorbed water around gel particles, swelling is due to the adsorption of water by the cement gel. The water molecules act against the cohesive force and tend to force the gel particles further apart as a result of which swelling takes place. In addition, the ingress of water decreases the surface tension of the gel.

The property of swelling when placed in wet condition, and shrinking when placed in drying condition is referred as moisture movement in concrete.

SULPHATE ATTACK:

Sulphates present in soil or water can cause serious damages to concrete. The methods given below can be adopted to protect concrete from sulphate attack.

USE OF SULPHATE RESISTING CEMENT

The most efficient method of resisting the sulphate attack is to use cement with the low C_3A

content. It has been found that a C_3A content of 7% gives a rough division between cement of good and poor performance in sulphate waters.

QUALITY CONCRETE

A well designed, placed and compacted concrete which is dense and impermeable exhibits a higher resistance to sulphate attack. Similarly, a concrete with low water/cement ratio also demonstrates a higher resistance to sulphate attack.

USE OF AIR-ENTRAINED ADMIXTURE

Use of air-entrainment to the extent of about 6% has beneficial effect on the sulphate resisting qualities of concrete. The beneficial effect is possibly due to reduction of segregation, improvement in workability, reduction in bleeding and in general better impermeability of concrete.

USE OF POZZOLANA

Incorporation of or replacing a part of cement by a pozzolanic material reduces the sulphate attack. Admixing of Pozzolana converts the leachable calcium hydroxide into non-leachable cementitious product. This pozzolanic action is responsible for impermeability of concrete. Secondly the removal of calcium hydroxide reduces the susceptibility of concrete to attack by magnesium sulphate.

HIGH PRESSURE STEAM CURING

High pressure steam curing improves the resistance of concrete to sulphate attack. This improvement is due to the change of C_3AH_6 into a less reactive phase and also to the removal or reduction of calcium hydroxide by the reaction of silica which is invariably mixed when high pressure steam curing method is adopted.

USE OF HIGH ALUMINA CEMENT

The cause of great resistance shown by high alumina cement to the action of sulphate is still not fully understood. However, it is attributed in part to the absence of any free calcium hydroxide in the set cement, in contrast to Portland cement. High alumina cement contains approximately 40% alumina, a compound very susceptible to sulphate attack, when in normal Portland cement. But this percentage of alumina present in high alumina cement behaves in a different way. The primary cause of resistance is attributed to formation of protective films which inhibit the penetration or diffusion of sulphate ions into the interior. It should be remembered that high alumina cement may not show higher resistance to sulphate attack at higher temperature.

Chlorides:

Chlorides are generally acidic in nature and can come from a number of different sources, the most common being, de-icing salts, use of unwashed marine aggregates, sea water spray, and certain accelerating admixtures (their use is now prohibited).

In the presence of chlorides localized pitting corrosion occurs which does not always have associated with it the early warning signs of surface cracking.

Chlorides induced corrosion is potentially more dangerous than that resulting from carbonation. Like most of the aspects of concrete durability, deterioration due to corrosion of the reinforcement can take place years (5 to 20) to manifest itself.

Chloride Attack on Concrete Structures:

Chloride attack is one of the most important aspects for consideration when we deal with the durability of concrete. Chloride attack is particularly important because it primarily causes corrosion of reinforcement. Statistics have indicated that over 40 per cent of failure of structures is due to corrosion of reinforcement.

Due to high alkalinity of concrete a protective oxide film is present on the surface of steel reinforcement. The protective passivity layer can be lost due to carbonation. This protective layer also can be lost due to the presence of chloride in the presence of water and oxygen. In reality the action of chloride in inducing corrosion of reinforcement is more serious than any other reasons. One may understand that Sulphates attack the concrete whereas the chloride attacks steel reinforcements.

Chloride enters the concrete from cement, water, and aggregate and sometimes from admixtures. The present day admixtures are generally containing negligible quantity of chloride or what they call chloride free. Chloride can enter the concrete by diffusion from environment. The Bureau of Indian Standard earlier specified the maximum chloride content in cement as 0.05 percent. But it is now increased the allowable chloride content in cement to 0.1 per cent. I S 456 of 2000 limits the chloride content as (Cl) in the concrete at the time of placing is shown in table-1.

S. No.	Type of Use of Concrete	Maximum Total acid soluble chloride content. Expressed as kg/m^3 of concrete
1	Concrete containing metal and steam cured at elevated temperature and prestressed concrete.	0.4
2	Reinforced concrete or plain concrete containing embedded metal.	0.6
3	Concrete not containing embedded metal or any material requiring protection from chloride.	3.0

The amount of chloride required for initiating corrosion is partly dependent on the pH value of the pore water in concrete. At a pH value less than 11.5 corrosion may occur without the presence of chloride. At pH value greater than 11.5 a good amount of chloride is required.

CORROSION OF STEEL?

The term *corrosion* is defined as an act or process of gradual wearing away of a metal due to chemical or **electro-chemical** reaction by its surroundings such that the metal is converted into an oxide, salt or some other compound. A substance known as *rust* results from such a process. In other words, the corrosion indicates the deterioration and loss of material due to chemical attack.

Causes of Corrosion of Steel Reinforcement in Concrete:

Corrosion of steel in concrete is an electrochemical process. The electrochemical potentials to form the corrosion cells may be generated in two ways:

(a) Composition cells may be formed when two dissimilar metals are embedded in concrete, such as steel rebars and aluminum conduit pipes, or when significant variations exist in surface characteristics of the steel.

(b) Concentration cells may be formed due to differences in concentration of dissolved ions near steel, such as alkalies, chlorides, and oxygen.

The differences in electrochemical potential can arise from differences in the environment of the concrete. Electrochemical cells form also due to a variation in salt concentration in the pore water or due to a non-uniform access to oxygen.

Thus, one of the two metals (or some parts of the metal when only one metal is present) becomes anodic and the other cathodic. The fundamental chemical changes occurring at the anodic and cathodic areas are as follows.

When there exists a difference in electrical potential along the steel in concrete, an electrochemical cell is set up: there form anodic and cathodic regions, connected by the electrolyte in the form of the pore water in the hardened cement paste.

The positively charged ferrous ions Fe^{++} at the anode pass into solution while the negatively charged free electrons e^- pass through the steel into the cathode where they are absorbed by the constituents of the electrolyte and combine with water and oxygen to form hydroxyl ions $(OH)^-$. These travels through the electrolyte and combine with the ferrous ions to form ferric hydroxide which is converted by further oxidation to rust. The reactions involved are as follows:

Anodic reactions:

$Fe \rightarrow Fe^{++} + 2e^-$

$Fe^{++} + 2(OH)^- \rightarrow Fe(OH)_2$ (ferrous hydroxide)

$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3$ (ferric hydroxide)

(Water) (Air) $2Fe(OH)_3 \rightarrow Fe_2 \times O_3 \times H_2O + 2H_2O$ — Hydrated ferric oxide (rust).

Cathodic reaction:

$4e^- + O_2 + 2H_2O \rightarrow 4(OH)^-$

It can be seen that oxygen is consumed and water is regenerated but it is needed for the process to continue. Thus, there is no corrosion in, dry concrete, probably below a relative humidity of 60 percent; nor is there corrosion in concrete fully immersed in water, except when water can entrain air, for example by wave action.

The transformation of metallic iron to rust is accompanied by an increase in volume, which depending on the state of oxidation, may be as large as 600 percent of the original metal. This volume increase is believed to be the principal cause of concrete expansion and cracking. It should be noted that the anodic reaction involving ionization of metallic iron will not progress far unless the electron flow to the cathode is maintained by consumption of the electrons at the cathode; for this the presence of both air and water at the surface of the cathode is absolutely necessary.

In the absence of chloride ions in the solution, the protective film on steel is reported to be stable if the pH of the solution stays above 11.5. Normally there is sufficient alkalinity in the system to maintain the pH above 12. In exceptional conditions (e.g., when concrete has high permeability and alkalies and most of the calcium hydroxide are either carbonated or neutralized by an acidic solution), the pH of concrete near steel may be reduced to less than 11.5, thus destroying the passivity of steel and setting the stage for the corrosion process.

In the presence of chloride ions, depending on the $C1^{-}$ / OH^{-} ratio, it is reported that the protective film may be destroyed even at pH values considerably above 11.5.

For corrosion to be initiated, the passivity layer must be penetrated. Chloride ions activate the surface of the steel to form an anode, the passivated surface being the cathode. The reactions involved are as follows:

$Fe^{++} + 2Cl^{-} \rightarrow FeCl_2$

$FeCl_2 + 2H_2O \rightarrow Fe(OH)_2 + 2HCl$

Carbonation of Embedded Steel

It is recognized that steel embedded in a heavily alkaline medium with pH values from 9 upwards will not rust. During the setting of concrete, cement begins to hydrate, this chemical reaction between cement and water in the concrete causes calcium hydroxide to be formed from the cement clinker. This ensures the concrete's alkalinity, producing a pH value of more than 12.6 which renders the steel surface passive.

Protection of the reinforcement from corrosion is thus provided by the alkalinity of the concrete, which leads to passivation of the steel. The reserve of calcium hydroxide is very high, so there is no need to expect steel corrosion even when water penetrates to the reinforcement of the concrete. because of this, even the occurrence of small cracks (up to 0.1 mm in width) or blemishes in the concrete need not necessarily lead to damage.

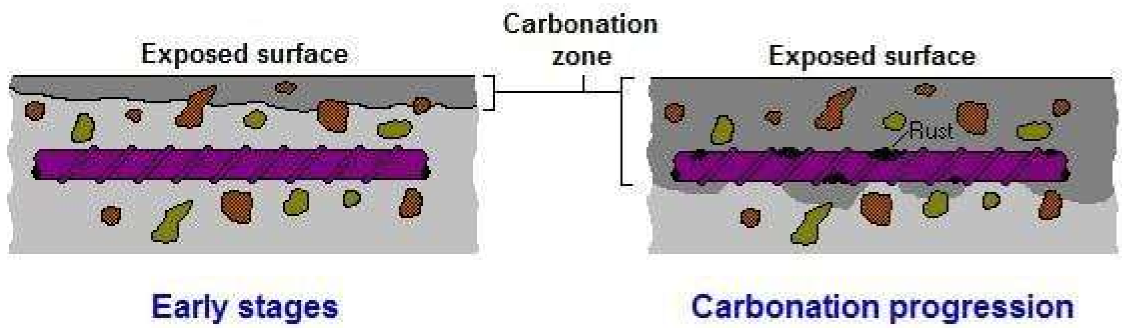
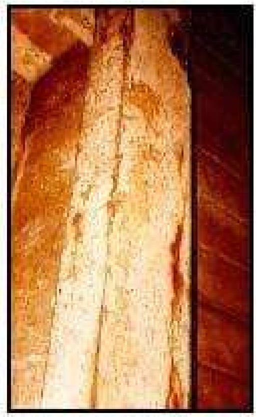


Fig.5.3: Carbonation leads to the general corrosion along the full length of the bar.



The above figure shows the first outward signs of general corrosion taking place is surface cracking of the concrete along the line of the steel.

The above fig. shows that as the corrosion proceeds, the concrete will spall away completely to expose the steel.

Environmental influences and carbon dioxide in particular, will reduce the concrete's pH value (carbonation) and thus removed the passivating effect, in conjunction with existing humidity, the result is corrosion of the reinforcement.

Carbonation is the effect of CO_2 from the atmosphere reacting with alkaline component in concrete $Ca(OH)_2$ in the presence of moisture thereby converting the calcium hydroxide to $CaCO_3$. The calcium carbonate is slightly soluble in water.
The pH value of the pore water is generally between 12.5 to 13.5 but due to carbonation the pH is

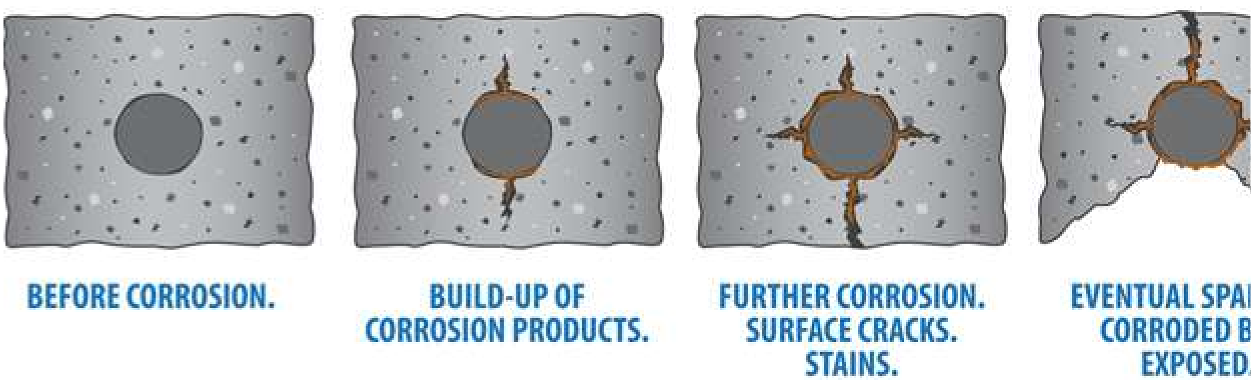
reduced to less than 9. The reinforcement therefore is no longer in the passivating range and corrosion occurs. The corrosion is accelerated in the presence of further moisture and oxygen.

$Ca(OH)_2 + CO_2 + H_2O = CaCO_3 + 2\ H_2O$

The process of carbonation reaches the depth of cover.

The factors influencing the depth of carbonation are:

1. Depth of cover
2. Permeability of concrete
3. Grade of concrete
4. Time
5. Whether the concrete is protected or unprotected
6. The environmental influences.
7. The ultimate result cracking, spalling and corrosion.



The corrosion cycle of steel begins with the rust expanding on the surface of the bar and causing cracking near the steel/concrete ir As time marches on, the corrosion products build up and cause more extensive cracking until the concrete breaks away from the bar eventually causing spalling.

Factors Influencing Corrosion of Steel Reinforcement

The factors which generally influence corrosion of reinforcement in RC structures are:

1. pH value,

2. Moisture,
3. Oxygen,
4. Carbonation,
5. Chlorides,
6. Ambient temperature and relative humidity,
7. Severity of exposure,
8. Quality of construction materials,
9. Quality of concrete,
10. Cover to the reinforcement,
11. Initial curing conditions, and
12. Formation of cracks.

Damages to Concrete Due to Corrosion of Steel Reinforcement:

The process of corrosion, once set off, results in deterioration and distress of the RC member. The various stages of destruction are as follows:

Stage 1: Formation of white patches

If the reinforcement is embedded in a concrete which is pervious enough to allow the passage of water and carbon dioxide then carbonation advances from surface to interior concrete. Carbon dioxide reacts with calcium hydroxide in the cement paste to form calcium carbonate. The free movement of water carries the unstable calcium carbonates towards the surface and forms white patches. The white patches at the concrete surface indicate the occurrence of carbonation.

Stage 2: Brown patches along reinforcement

When reinforcement starts corroding, a layer of ferric oxide is formed on the reinforcement surface. This brown product resulting from corrosion may permeate along with moisture to the concrete surface without cracking of the concrete. Usually it accompanies cracking or cracking of the concrete occurs shortly thereafter.

Stage 3: Occurrence of cracks

The products of corrosion normally occupy a much greater volume about 6 to 10 times than the parent metal. The increase in volume exerts considerable bursting pressure on the surrounding concrete resulting in cracking.

The hair line crack in the concrete surface lying directly above the reinforcement and running parallel to it is the positive visible indication that reinforcement is corroding. These cracks indicate that the expanding rust has grown enough to split the concrete. Even at this stage the reinforcement looks as though it is rust free if the concrete is chipped off.

Stage 4: Formation of multiple cracks

As corrosion progresses, there will be formation of multiple layers of ferric oxide on the reinforcement which in turn exert considerable pressure on the surrounding concrete resulting in widening of hair cracks. In addition, several new hair cracks are also formed. The bond between concrete and the reinforcement is considerably reduced. There will be a hollow sound when the concrete is tapped at the surface with a light hammer.

Stage 5: Spalling of cover concrete

Due to loss in bond between steel and concrete and formation of multiple layers of scales, the cover concrete starts peeling off. At this stage, there is considerable reduction of the size of the bar.

Stage 6: Snapping of bars

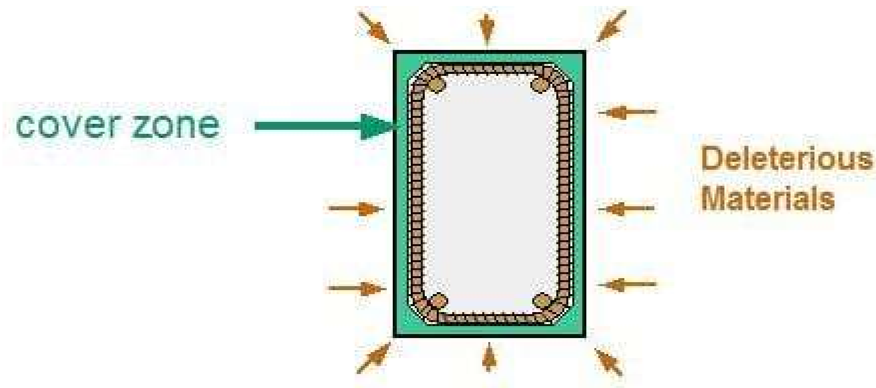
The continued reduction in the size of bars, results in snapping of the bars. Usually snapping occurs in ties / stirrups first. At this stage, there will also be a considerable reduction in the size of the main bars.

Stage 7: Buckling of bars and bulging of concrete

The spalling of the cover concrete and snapping of ties (in compression member) causes the main bars to buckle, thus resulting in the bulging of concrete in that region. This follows a collapse of the structure.

Minimizing the Risk of Steel Reinforcement Corrosion

The quality and depth of concrete in the cover zone are all important in minimizing the risk of corrosion as shown in fig. below.



Quality of Concrete

Quality is controlled largely by minimizing permeability.

Depth of Reinforcement Steel Cover

Recommendations for minimum depths of cover are given in the codes of practice and are based on exposure conditions and minimum cement contents. Higher cement contents infer lower water cement rations leading to permitted reductions in cover.

At no time should the normal cover be less than the maximum size of aggregates+5mm.

Materials of Concrete Construction

Blended cements made from combinations of PC/PFA and PC/GGBS can lead to significant reduction in chloride penetration. However, in situations where these materials are not cured properly there is a risk of increased carbonation. Care must be taken that all aggregates and admixtures contain limited amount of chlorides.

HOW TO PREVENT CORROSION OF STEEL IN CONCRETE?

The steel is the most liable to the corrosion and hence the study of steel corrosion is of paramount importance. To minimize the chances of development of corrosion of steel in concrete, the following preventive measures may be taken.

1. Avoiding heavily congested reinforcement especially at the intersection of beams and columns.
2. Avoiding the steel to come into contact with bricks, soil, wood and other porous non-alkaline materials
3. Avoiding the use of materials which accelerate the process of corrosion i.e. aggregates with high salt contents, water containing salts, etc.
4. Cleaning the reinforcement with wire-brush to remove the rust scales before placing of concrete

5. Maintaining a high degree of workmanship.
6. Proper structural design with due provision of cover.
7. Providing cathodic protection to the reinforcement by some suitable method.
8. Providing surface coatings with paints, tars, asphalts, etc
9. Use of high quality and impermeable concrete.
10. Using stone pebbles in place of badly made cover blocks.
11. Using the correct water-cement ratio.

MEASURES TO CONTROL THE CORROSION OF STEEL REINFORCEMENT:

They are listed and briefly explained.

1. metallurigical methods: steel can be made more corrosion resistant by altering its structure through metallurgical process. Different methods such as rapid quenching of the hot bars by series of water jets, or by keeping the hot steel bars for a short time in a water bath, and by such other process the mechanical properties and corrosion resistance property of steel can be improved. There may be many situations where stainless steel reinforcements are used for long term durability of concrete.

2. corrosion inhibitors: corrosion can be prevented or delayed by chemical method by using certain corrosion inhibiting chemicals such as nitrites, phosphates, benzoates etc. of the available materials, the most widely used admixture is based on calcium nitrite. It is added to the concrete during mixing of concrete during mixing of concrete. The typical dosage is of the order of 10-30 litres per cum of concrete depending on chloride levels in concrete.

3. coatings to reinforcement: The object of coating to steel bar is to provide a durable barrier to aggressive materials such as chlorides. The coatings should be robust to withstand fabrication of reinforcement cage, and pouring of concrete and compaction by vibrating needle.

Simple cement slurry coating is a cheap method for temporary protection against rusting of reinforcement in storage.

Concrete Coating and Sealers: When untreated reinforcing bar is used, the best method is to apply protective coatings to concrete surface to seal entry of moisture, carbon dioxide and chlorides. The dry concrete surface should be roughened by chiseling, and a workable mixture of 1:3 cement sand mortar should be applied on the concrete surface after watering over the surface properly by trowelling to a thickness of 6 mm. The surface should be finished with neat cement slurry consisting of water and cement in ratio 2:1.

Galvanizing reinforcement: galvanizing of reinforcement consists of dipping the steel bars in molten zinc. This result in a coating of zinc bonded to the surface of steel. The zinc surface reacts with calcium hydroxide in the concrete to form a passive layer and prevent corrosion.

Fusion Bonded Epoxy Coating (FBEC) : Today the world over, Fusion Bonded Epoxy Coating (FBEC) has proved to be most effective reliable and long-term economical method of anti-corrosive treatment for reinforcing bars. It is applied directly on the reinforcing steel which presents corrosion by isolating and insulating the steel from the corrosive environment. These coatings protect against external and internal corrodents.

Coating of Rebars: The corrosion of rebars can be prevented by applying proper coating to rebars. The coating can be one of the following (i) Paint (ii) Chemical Compounds (iii) Metallic Epoxy Coating and (iv) Fusion Bonded

Assignment-Cum-Tutorial Questions

A. Questions testing the remembering / understanding level of students

I) Objective Questions

1. Creep coefficient of at one year age is about

(a) 3.3 (b) 2.2 (c) 4.4 (d) 1.1

2. The shrinkage of concrete is due to change in

(a) length (b) cross sectional area (c) volume (d) surface area

3. Concrete shrinkage is more pronounced in

(a) rich mix (b) lean mix (c) very lean mix (d) normal mix

4. The timedependent phenomenon in concrete is

(a) gain of strength (b) shrinkage (c) creep (d) all of the above

5. Creep of concrete is influenced by

(a) strength of concrete (b) age of concrete (c) w/c ratio (d) all of the above

6. The ratio of ultimate creepstrain to elastic strain is known as

(a) creep modulus (b) creep coefficient (c) creep strain ratio (d) tertiary creep

7. The shrinkage strain in concrete is approximately

(a) 0.0030 (b) 0.0300 (c) 0.0003 (d) 0.3000

II) Descriptive Questions

1. Define creep?
2. Define shrinkage?
3. Define poission’s ratio?
4. What is meant by modulus of elasticity?
5. What is meant by corrosion of steel?
6. What are the control methods of corrosion of steel?

B. Questions testing the ability of students in applying the concepts.

I) Multiple Choice Questions:

1.The presence of common salt in sand results in

(a) Corrosion of reinforcement (b) scaling (c) pitting (d) all of the above

2.Modulus of elasticity of concrete increases with the

(a) Age (b) increase in w/c ratio (c) decrease is curing period (d) all of the above

3. The corrosion of steel in concrete is faster when the element is immersed in

(a) alkaline solution (b) acidic solution (c) sea water (d) none of the above

4. Carbonation of concrete results into

(a) Increased shrinkage (b) increased strength (c) both of the above (d) increased permeability

5. As per IS: 456-2000, the modulus of elasticity of concrete is taken as

(a) 5700 (b) 5000 (c) 570 (d) 50

6. As per IS: 456-2000, the relationship b/w modulus of rupture ( ) and characteristics of strength of concrete) is

(a) 0.070 (b) (c) 0.70 (d)

7. Shrinkage in concrete increases its

(a) Tensile strength (b) flexural strength (c) bond strength (d) compressive strength

II) Descriptive Questions

1. Write short notes on sulphate attack?
2. Explain different moduli of elasticity.
3. What are the factors affecting on creep?
4. What are the methods of controlling sulphate attack?
5. Explain the types of shrinkage?
6. Which factors affecting on cracks in concrete?
7. Explain the relation between creep and time?

C. Questions testing the analyzing /evaluating ability of students

1. Differentiate the behavior of creep and shrinkage of concrete.

2. Explain the new controlling factors of corrosion of steel bars.

D. GATE/ Competitive oriented bits

1. Creep in concrete is undesirable particularly in

(a) RCC columns (b) continuous beams (c) prestressed structures (d) all of the above

2. Shrinkage in concrete can be reduced by using

(a) Low w/c ratio (b) presaturated aggregates (c) light and non absorbent form (d) above all

3. Modulus of elasticity for concrete improves by

(a)shorter curing periods (b) higher w/c ratio (c) age (d) all of the above

4. The poisson's ratio for concrete lies b/w

(a)0.15 and 0.25 (b) 0.25 and 0.30 (c) 0.30 and 0.35 (d) 0.35 and 0.38

5.The ratio of youngs modulus of elasticity for steel to that for concrete is known as

(a) specific ratio (b) modular ratio (c) elasticity ratio (d) poisson's ratio

6. The mild steel to be used as a reinforcing material should be free from

(a) loose mill scale (b)oil and grease (c) loose rust (d) all of the above (e) all of the above

UNIT – VI

Concrete Technology

Objective: To understand quality control aspects, acceptance criteria and method of mix design.

Syllabus: MIX DESIGN: Factors in the choice of mix proportions- Durability of concrete- quality control of concrete- Statistical methods- acceptance criteria- proportioning of concrete mixes by BIS method of mix design.

Learning outcomes:

Students will be able to

- design the mix for given grade of concrete
- apply quality control aspects

INTRODUCTION:

Factors influencing the choice of concrete mix proportions:

Mix Proportion:

The mix proportions shall be selected to ensure the workability of the fresh concrete and when concrete is hardened, it shall have the required strength, durability and surface finish.

The determination of the proportions of cement aggregates and water to attain the required strengths shall be made as follows;

a) By designing the concrete mix; such concrete shall be called **'Design mix concrete'**, or

b) By adopting nominal concrete mix; such concrete shall be called **'Nominal mix concrete'**.

Design mix concrete is preferred to nominal mix. If design mix concrete cannot be used for any reason on the work for grades of M 20 or lower, nominal mixes may be used with the permission of engineer-in-charge, which, however, is likely to involve higher cement content.

In specifying a particular grade of concrete, the following factors considered in the choice of mix proportions:

a) Type of mix, that is, design mix concrete or nominal mix concrete;

b) Grade designation (M10, M20, M30, M40….)

c) Type of grade of cement (OPC 33, 43 & 53 grades)

d) Maximum nominal size of aggregate & grading of combined aggregates

e) Minimum cement content (for design mix concrete);

f) Maximum water-cement ratio

g) Workability

h) Mix proportion (for 'nominal mix concrete)

j) Exposure conditions (mild, moderate, severe, extreme, and very severe)

k) Maximum temperature of concrete at the time of placing

m) Method of placing and

n) Degree of supervision.

In appropriate circumstances, the following additional information may be specified:

a) Type of aggregate

b) Maximum cement content

c) Whether an admixture shall or shall not be used and the type of admixture and the condition of use.

Durability of Concrete: The durability of cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. Durable concrete will retain its original form, quality, and serviceability when exposed to its environment.

One of the main characteristics influencing the durability of concrete is its permeability to the ingress of water, oxygen, carbon dioxide, chloride, sulphate and other potentially deleterious substances. Impermeability is governed by the constituents and workmanship used in making the concrete. With normal-weight aggregates a suitably low permeability is achieved by having an adequate cement content, sufficiently low free water/cement ratio, by ensuring complete compaction of the concrete, and by adequate curing.

The factors influencing durability include:

a) The environment
b) The cover to embedded steel
c) The type and quality of constituent materials
d) The cement 'content and water/cement ratio of the concrete.
e) Workmanship, to obtain full compaction and efficient curing
f) The shape and size of the member.
Significance of Durability

When designing a concrete mix or designing a concrete structure, the exposure condition at which the concrete is supposed to withstand is to be assessed in the beginning with good judgment. In case of foundations, the soil characteristics are also required to be investigated. The environmental pollution is increasing day by day particularly in urban areas and industrial atmospheres. It is reported that in industrially developed countries over 40 per cent of total resources of the building industries are spent on repairs and maintenance. In India, the money that is spent on repair of buildings is also considerable. Every government department and municipal bodies have their own "Repair Boards" to deal with repairs of buildings. We carry out repairs job in a casual manner using only ordinary cement mortar practiced decades back. Today, special repair materials and techniques are available. The use of such materials makes the repair job more effective and durable.

QUALITY CONTROL OF CONCRETE: Before we deal with some of the important methods of concrete mix design, it is necessary to get acquainted with statistical quality control methods, which are common to all the methods of mix design.

Statistical Quality Control of Concrete

Concrete like most other construction processes, have certain amount of variability both in materials as well as in constructional methods. This results in variation of strength from batch to batch and also within the batch. It becomes very difficult to assess the strength of the final product. It is not possible to have a large number of destructive tests for evaluating the strength of the end products and as such we have to resort to sample tests. It will be very costly to have very rigid criteria to reject the structure on the basis of a single or a few standard samples. The basis of acceptance of a sample is that a reasonable control of concrete work can be provided, by ensuring that the probability of test result falling below the design strength is not more than a specified tolerance level. The aim of quality control is to limit the variability as much as practicable. Statistical quality control method provides a scientific approach to the concrete designer to understand the realistic variability of the materials so as to lay down design specifications with proper tolerance to cater for unavoidable variations. The acceptance criteria are based on statistical evaluation of the test result of samples taken at random during execution. By devising a proper sampling plan it is possible to ensure a certain quality at a specified risk. Thus the method provides a scientific basis of acceptance which is not only realistic but also restrictive as required by the design requirements for the concrete construction.

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Common Terminologies

The common terminologies that are used in the statistical quality control of concrete are explained below.

(a) Mean strength:

This is the average strength obtained by dividing the sum of strength of all the cubes by

the number of cubes.

where x = mean strength

Σx = sum of the strength of cubes

n = number of cubes.

(b) Variance: This is the measure of variability or difference between any single observed data from the mean strength.

(c) Standard deviation: This is the root mean square deviation of all the results. This is denoted by s or σ.

Numerically it can be explained as,

where σ = Standard deviation,

n = number of observations

x = particular value of observations

x = arithmetic mean.

Standard deviation increases with increasing variability. The characteristics of the normal distribution curve are fixed by the average value and the standard deviation. The spread of the curve along the horizontal scale is governed by the standard deviation, while the position of the curve along the vertical scale is fixed by the mean value.

(d) Coefficient of variation: It is an alternative method of expressing the variation of results. It is a non-dimensional measure of variation obtained by dividing the standard deviation by the arithmetic mean and is expressed as:

where v = coefficient of variation.

Acceptance Criteria

Compressive strength:

The concrete is deemed to comply with the compressive strength requirements when both the following conditions are met,

(a) The mean strength determined from any group of four consecutive test results complies with the appropriate limits in column 2 of Table 11.27.

(b) Any individual test result complies with the appropriate limits in column 3 of Table 11.27

Table 1 Characteristic Compressive Strength Compliance Requirements as per IS 456—2000 (as amended)

Specified Grade	Mean of the Group of 4 Non-overlapping Consecutive Test Results in N/mm^2	Individual Test Results in N/mm^2
(1)	(2)	(3)
M 15	$\geq f_{ck}$ + 0.825 x established standard deviation (rounded off to the nearest 0.5 N/mm^2) or f_{ck} + 3 N/mm^2 whichever is greater	$\geq f_{ck}$ − 3 N/mm^2
M 20 or above	$\geq f_{ck}$ + 0.825 x established standard deviation (rounded off to the nearest 0.5 N/mm^2) or f_{ck} + 3 N/mm^2 whichever is greater	$\geq f_{ck}$ − 3 N/mm^2

Flexural strength:

When both the following conditions are met, the concrete complies with the specified flexural strength.

(a) The mean strength determined from any group of four consecutive test results exceeds the specified characteristic strength by at least 0.3 N/mm2

(b) The strength determined from any test result is not less than the specified characteristic strength less 0.3 N/mm2

- ❖ **Concrete mix design procedure is available in IS: 10262-2009 code book**

Assignment-Cum-Tutorial Questions

A. Questions testing the remembering / understanding level of students

I) Objective Questions

1. The measure of variation in statistical quality control of concrete is generally determined by(a) coefficient of variation (b) coefficient of friction (c) standard deviation (d) variance
2. The grade of concrete for RCC for sea water application shall not be less than
   (a) M15 (b) M20 (c) M30 (d) M10
3. The nominal mix corresponding to M20 grade of concrete is
   (a) 1:1.5:3 (b) 1:2:4 (c) 1:3:6 (d) 1:2:3
4. The nominal mix corresponding to M10 grade of concrete is
   (a) 1:1.5:3 (b) 1:2:4 (c) 1:3:6 (d) 1:2:3
5. The nominal mix corresponding to M15 grade of concrete is
   (a) 1:1.5:3 (b) 1:2:4 (c) 1:3:6 (d) 1:2:3

II) Descriptive Questions

1. What is durability of concrete?

2. What is the quality control of concrete?

3. What are the acceptance criteria for a mix design?

4. What are the different factors in the choice of mix proportions?
5. Define nominal mix of concrete and design mix of concrete.

B. Questions testing the ability of students in applying the concepts.

I) Multiple Choice Questions:

1. The total no of grades of ordinary concrete stipulated in IS:456-2000 are

(a) 3 (b) 7 (c) 5 (d) 10

2. The total no of grades of standard concrete stipulated in IS:456-2000 are
   (a) 3 (b) 7 (c) 5 (d) 10
3. The total no of grades of high strength concrete stipulated in IS:456-2000 are
   (a) 3 (b) 7 (c) 5 (d) 10
4. For slabs and beams, the concrete of nominal mix generally used is
   (a) 1:1.5:3 (b) 1:2:4 (c) 1:3:6 (d) 1:2:3
5. For water retaining structures the nominal mix generally used in is
   (a) 1:1:2 (b) 1:2:4 (c) 1:3:6 (d) 1:2:3

II) Descriptive Questions

1. Design a concrete mix of M30 grade for a roof slab. Take a Standard deviation of 5MPa. The specific gravities of Coarse Aggregate and Fine Aggregate are 2.74 and 2.62 respectively. The bulk density of coarse aggregate is 1620kg/m3 and fineness modulus of fine aggregate is 2.76. A slump of 65mm is necessary. The water absorption of coarse aggregate is 1% and free moisture in fine aggregate is 2%. Design the concrete mix using IS code method. Assume any missing data suitably.

2. Design a concrete mix of M35 grade for a roof slab. Take a Standard deviation of 5MPa. The specific gravities of Coarse Aggregate and Fine Aggregate are 2.76 and 2.59 respectively. The bulk density of coarse aggregate is 1625kg/m3 and fineness modulus of fine aggregate is 2.82. A slump of 70mm is necessary. The water absorption of coarse aggregate is 1% and free moisture in fine aggregate is 2%. Design the concrete mix using IS code method. Assume any missing data suitably.

3. Design a concrete mix for characteristic strength of 25MPa at 28 days with a standard deviation of 4MPa.The specific gravity of FA and CA are 2.62 and 2.74 respectively. A slump of 40mm is necessary. The specific gravity of cement is 3.12.Assuming the necessary data design the mix as per IS code method

C. Questions testing the analyzing /evaluating ability of students

1. Design a concrete mix for the slab of a residential building a roof slab. with the following data. Take a Standard deviation of 4MPa. The specific gravities of Coarse Aggregate and Fine Aggregate are 2.73 and 2.60 respectively. The bulk density of coarse aggregate is 1615kg/m3 and fineness modulus of fine aggregate is 2.74. A slump of 55mm is necessary. The water absorption of coarse aggregate is 1% and free moisture in fine aggregate is 2%. Design the concrete mix using IS code method. Assume any missing data suitably.

2. Design a concrete mix for industrial structure with the following data. Take a Standard deviation of 4MPa. The specific gravities of Coarse Aggregate and Fine Aggregate are 2.75 and 2.58 respectively. The bulk density of coarse aggregate is 1630kg/m3 and fineness modulus of fine aggregate is 2.78. A slump of 60mm is necessary. The water absorption of coarse aggregate is 1% and free moisture in fine aggregate is 2%. Design the concrete mix using IS code method.

Assume any missing data suitably.

3. Explain in detail the various steps involved in designing concrete mixes using B.I.S. method.

D. GATE/ Competitive oriented bits

1. The assumed standard deviation value for M15 grade of concrete is

(a) 3.5 (b) 4 (c) 4.5 (d) 5

2. The assumed standard deviation value for M20 grade of concrete is

(a) 3.5 (b) 4 (c) 4.5 (d) 5

3. The assumed standard deviation value for M50 grade of concrete is

(a) 3.5 (b) 4 (c) 4.5 (d) 5

4. According to IS 456-2000 How many Environmental exposure conditions are available

(a) 3 (b) 4 (c) 5 (d) 8

5. For one bag of cement (50 kg) the quantity of water required would be

(a) 50 kg (b) 35 kg (c) 25kg (d) 15kg

6. Which one the following is not required in mix design of concrete?

(a) Quality control (b) workability of concrete (c) compressive strength (d) initial setting time