Syllabus:

UNIT -I

CEMENTS & ADMIXTURES: Portland cement – chemical composition – Hydration, Setting of cement – Structure of hydrated cement – Test`s on physical properties –Different grades of cement – Admixtures – Mineral and chemical admixtures.

AGGREGATES: Classification of aggregate – Particle shape & texture – Bond, strength& other mechanical properties of aggregate – Specific gravity, Bulk density, porosity, Adsorption & 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 & Coarse Aggregates – Gap graded aggregate – Maximum aggregate size.

NOTES

INTRODUCTION:

Concrete technology deals with study of properties of **concrete** and its practical applications. ... Various types of cements are used for **concrete** works which have different properties and applications. Some of the type of **cement** are Portland Pozzolana **Cement** (PPC), rapid hardening **cement**, Sulphate resistant **cement.**

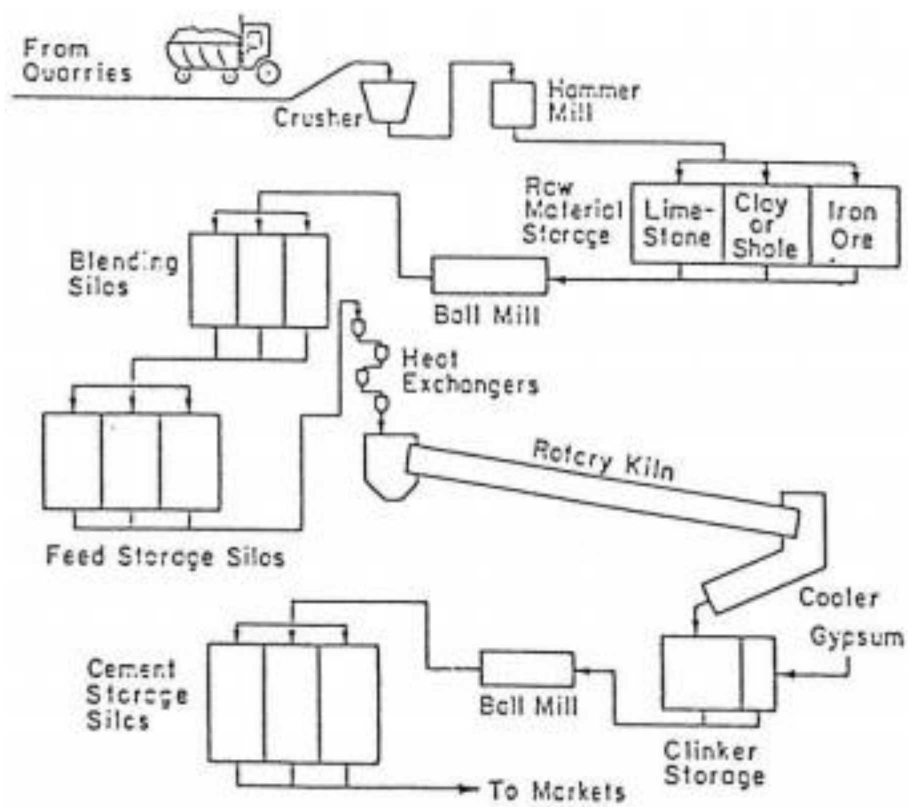
It addresses the properties of **concrete** needed in construction applications, including strength and durability, and provides guidance on all aspects of **concrete** from mix design to batching, mixing, transporting, placing, consolidating, finishing, and curing.

❖ Portland cement

Concrete is made by Portland cement, water and aggregates. Portland cement is a hydraulic cement that hardens in water to form a water-resistant compound. The hydration products act as binder to hold the aggregates together to form concrete. The name Portland cement comes from the fact that the colour and quality of the resulting concrete are similar to Portland stone, a kind of limestone found in England.

❖ Manufacture of Portland cement

Portland cement is made by blending the appropriate mixture of limestone and clay or shale together and by heating them at 1450ºC in a rotary kiln. The sequence of operations is shown in following figure. The preliminary steps are a variety of blending and crushing operations. The raw feed must have a uniform composition and be a size fine enough so that reactions among the components can complete in the kiln. Subsequently, the burned clinker is ground with gypsum to form the familiar grey powder known as Portland cement.



The raw materials used for manufacturing Portland cement are limestone, clay and Iron ore. a) Limestone (*CaCO3*) is mainly providing calcium in the form of calcium oxide (*CaO*)

$$CaCO3\ (1000^{o}C) \rightarrow CaO + CO2$$

b) Clay is mainly providing silicates (*SiO2*) together with small amounts of *Al2O3 + Fe2O3*

$$Clay\ (1450^{o}C) \rightarrow SiO2 + Al2O3 + Fe2O3 + H2O$$

c) Iron ore and Bauxite are providing additional aluminium and iron oxide (*Fe2O3*) which help the formation of calcium silicates at low temperature. They are incorporated into the raw mix.

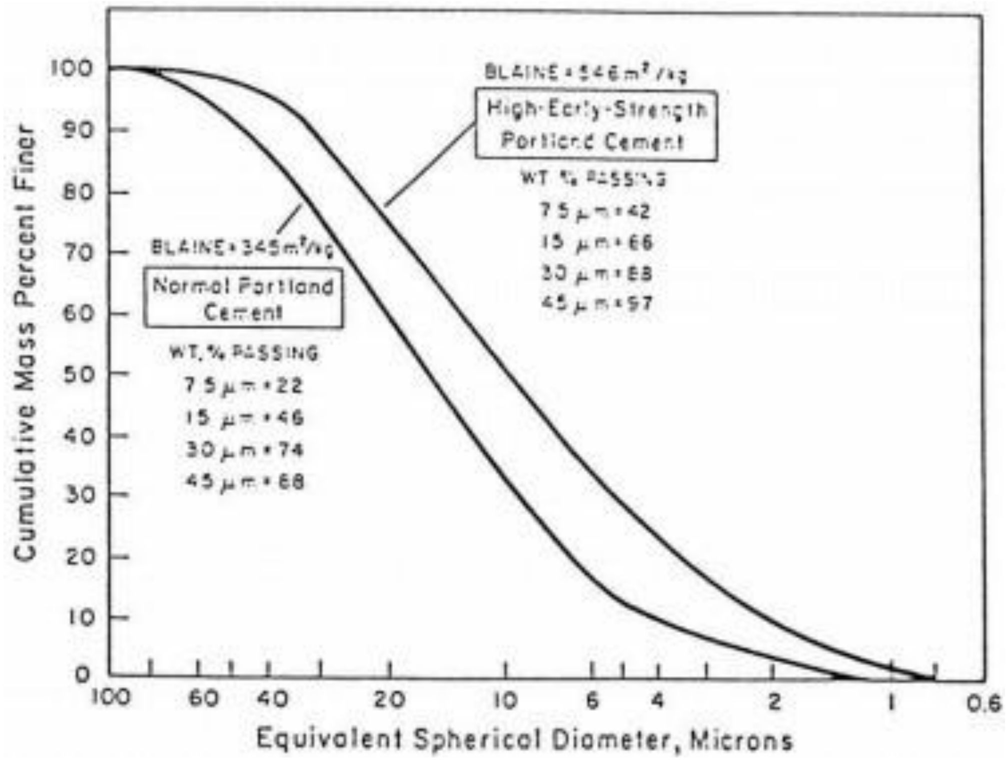
Limestone 3 $CaO^{o}SiO2$

High temperature 2 $CaO^{o}SiO2$

Iron Ore, Bauxite 4 $CaO^{o}Al_2O_3{}^{o}Fe_2O3$

d) The clinker is pulverized to small sizes (< 75 μm). 3-5% of gypsum (calcium sulphate) is added to control setting and hardening.

The majority particle size of cement is from 2 to 50 μm. A plot of typical particle size distribution is given below. (Note: "Blaine" refers to a test to measure particle size in terms of surface area/mass)



❖ Chemical composition

a) Abbreviation:

CaO = C, SiO2 = S, Al2O3 = A; Fe2O3 =F, Ca $(OH)_2$ = CH,

H2O = H, SO3 = *S* (sulphur trioxide)

Thus we can write 3 CaO = C3 and 2 CaO°SiO2 = C2S.

b) Major compounds:

Compound Oxide colour Common name Weight percentage composition

Tricalcium

Silicate C3S white Alite 50%

Dicalcium

Silicate C2S white Belite 25%

Tricalcium

Aluminate C3A white/grey --- 12%

Tetracalcium

Aluminoferrite C4AF black Ferrite 8%

Since the primary constituents of Portland cement are calcium silicate, we can define Portland cement as a material which combine CaO SiO2 in such a proportion that the resulting calcium silicate will react with water at room temperature and under normal pressure.

c) Minor components of Portland cement

The most important minor components are gypsum, MgO, and alkali sulphates.

Gypsum (*$2CaSO_4{}^o 2H2O$*) is an important component added to avoid flash set.

Alkalies (MgO, Na2O, K2O) can increase pH value up to 13.5 which is good for reinforcing steel protection. However, for some aggregates, such a high alkaline environment can cause alkali aggregate reaction problem.

❖ **Types of cement**

1) Ordinary Portland cement

Ordinary Portland cement (OPC) is by far the most important type of cement. All the discussions that we have done in the previous chapter and most of the discussions that are going to be done in the coming chapters relate to OPC. Prior to 1987, there was only one grade of OPC which was governed by IS 269-1976. After 1987 higher grade cements were introduced in India. The OPC was classified into three grades, namely 33 grade, 43 grade and 53 grade depending upon the strength of the cement at 28 days when tested as per IS 4031- 1988. If the 28 days strength is not less than $33N/mm^2$, it is called 33 grade cement, if the strength is not less than 43N/mm^2, it is called 43 grade cement, and if the strength is not less then 53 N/mm^2, it is called 53 grade cement. But the actual strength obtained by these cements at the factory are much higher than the BIS specifications.

The manufacture of OPC is decreasing all over the world in view of the popularity of blended cement on account of lower energy consumption, environmental pollution, economic and other technical reasons. In advanced western countries the use of OPC has come down to about 40 per cent of the total cement production. In India for the year 1998-99 out of the total cement production *i.e.*, 79 million tons, the production of OPC in 57.00 million tons *i.e.*, 70%. The production of PPC is 16 million tone*i.e.*, 19% and slag cement is 8 million tons*i.e.*, 10%. In the years to come the use of OPC may still come down, but all the same the OPC will remain as an important type for general construction.

2) Rapid Hardening Cement (IS 8041–1990)

This cement is similar to ordinary Portland cement. As the name indicates it develops strength rapidly and as such it may be more appropriate to call it as high early strength cement. It is pointed out that rapid hardening cement which develops higher rate of development of strength should not be confused with quick-setting cement which only sets quickly. Rapid hardening cement develops at the age of three days, the same strength as that is expected of ordinary Portland cement at seven days.

The rapid rate of development of strength is attributed to the higher fineness of grinding (specific surface not less than 3250 sq. cm per gram) and higher C_3S and lower C_2S content.

A higher fineness of cement particles expose greater surface area for action of water and also higher proportion of C_3S results in quicker hydration. Consequently, capid hardening cement gives out much greater heat of hydration during the early period. Therefore, rapid hardening cement should not be used in mass concrete construction.

The use of rapid heading cement is recommended in the following situations:

(a) In pre-fabricated concrete construction.

(b) Where formwork is required to be removed early for re-use elsewhere,

(c) Road repair works,

(d) In cold weather concrete where the rapid rate of development of strength reduces the vulnerability of concrete to the frost damage.

3) Extra Rapid Hardening Cement

Extra rapid hardening cement is obtained by intergrinding calcium chloride with rapid hardening Portland cement. The normal addition of calcium chloride should not exceed 2 per cent by weight of the rapid hardening cement. It is necessary that the concrete made by using extra rapid hardening cement should be transported, placed and compacted and finished within about 20 minutes. It is also necessary that this cement should not be stored for more than a month.

Extra rapid hardening cement accelerates the setting and hardening process. A large quantity of heat is evolved in a very short time after placing. The acceleration of setting, hardening and evolution of this large quantity of heat in the early period of hydration makes the cement very suitable for concreting in cold weather.

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Cement is about 25 per cent higher than that of rapid hardening cement at one or two days and 10–20 per cent higher at 7 days. The gain of strength will disappear with age and at 90 days the strength of extra rapid hardening cement or the ordinary portland cement may be nearly the same.

There is some evidence that there is small amount of initial corrosion of reinforcement when extra rapid hardening cement is used, but in general, this effect does not appear to be progressive and as such there is no harm in using extra rapid hardening cement in reinforced concrete work. However, its use in prestress concrete construction is prohibited.

In Russia, the attempt has been made to obtain the extra rapid hardening property by grinding the cement to a very fine degree to the extent of having a specific surface between 5000 to 6000 sq. cm/gm. The size of most of the particles are generally less than 3 microns[2.1]. It is found that this very finely ground cement is difficult to store as it is liable to air-set. It is not a common cement and hence it is not covered by Indian standard.

4) Sulphate Resisting Cement (IS 12330–1988)

Ordinary Portland cement is susceptible to the attack of sulphates, in particular to the action of magnesium sulphate. Sulphates react both with the free calcium hydroxide in set-cement to form calcium sulphate and with hydrate of calcium aluminate to form calcium sulphoaluminate, the volume of which is approximately 227% of the volume of the original aluminates. Their expansion within the frame work of hadened cement paste results in cracks and subsequent disruption. Solid sulphate do not attack the cement compound. Sulphates in solution permeate into hardened concrete and attack calcium hydroxide, hydrated calcium aluminate and even hydrated silicates.

The above is known as sulphate attack. Sulphate attack is greatly accelerated if accompanied by alternate wetting and drying which normally takes place in marine structures in the zone of tidal variations.

To remedy the sulphate attack, the use of cement with low C_3A content is found to be effective. Such cement with low C_3A and comparatively low C_4AF content is known as Sulphate Resisting Cement. In other words, this cement has a high silicate content. The specification generally limits the C_3A content to 5 per cent.

Tetracalcium Alumino Ferrite (C_3AF) varies in Normal Portland Cement between to 6 to 12%. Since it is often not feasible to reduce the Al_2O_3 content of the raw material, Fe_2O_3 may be added to the mix so that the C_4AF content increases at the expense of C_3A. IS code limits the total content of C_4AF and C_3A, as follows.

$2C_3A + C_4AF$ should not exceed 25%.

In many of its physical properties, sulphate resisting cement is similar to ordinary Portland cement. The use of sulphate resisting cement is recommended under the following conditions:

(a)) Concrete to be used in marine condition;

(b) Concrete to be used in foundation and basement, where soil is infested with sulphates;

(c) Concrete used for fabrication of pipes which are likely to be buried in marshy region or sulphate bearing soils;

(d) Concrete to be used in the construction of sewage treatment works.

5) Portland Slag Cement (PSC) (IS 455–1989)

PPC is obtained by mixing portland cement clinker and granulated blast furnace slag in suitable proportions and grinding the mixture to get a thorough and intimate mixture between the constituents. It may also be manufactured by separately grinding

Portland cement clinker, gypsum and ground granulated blast furnace slag and later mixing them intimately. The resultant product is a cement which has physical properties similar to those of ordinary Portland cement. In addition, it has low heat of hydration and is relatively better resistant to chlorides, soils and water containing excessive amount of sulphates or alkali metals, alumina and iron, as well as, to acidic waters, and therefore, this can be used for marine works with advantage.

Separate grinding is used as an easy means of verying the slag clinker proportion in the finished cement to meet the market demand. Recently, under Bombay Sewage disposal project at Bandra, they have used 70% ground granulated blast furnace slag (GGBS) and 30% cement for making grout to fill up the trench around precast sewer 3.5 m dia embedded 40 m below MSL.

Portland blast furnace cement is similar to ordinary Portland cement with respect to fineness, setting time, soundness and strength. It is generally recognised that the rate of hardening of Portland blast furnace slag cement in mortar or concrete is somewhat slower than that of ordinary Portland cement during the first 28 days, but thereafter increases, so that at 12 months the strength becomes close to or even exceeds those of Portland cement. The heat of hydration of Portland blast furnace cement is lower than that of ordinary Portland cement. So this cement can be used in mass concrete structures with advantage. However, in cold weather the low heat of hydration of Portland blast furnace cement coupled with moderately low rate of strength development, can lead to frost damage.

Extensive research shows that the presence of GGBS leads to the enhancement of the intrinsic properties of the concrete both in fresh and hardened states. The major advantages currently recognised are:

(a) Reduced heat of hydration;
(b) Refinement of pore structure;
(c) Reduced permeability;

6) Quick Setting Cement

This cement as the name indicates sets very early. The early setting property is brought out by reducing the gypsum content at the time of clinker grinding. This cement is required to be mixed, placed and compacted very early. It is used mostly in under water construction where pumping is involved. Use of quick setting cement in such conditions reduces the pumping time and makes it economical. Quick setting cement may also find its use in some typical grouting operations.

7) Super Sulphated Cement (IS 6909–1990)

Super sulphated cement is manufactured by grinding together a mixture of 80-85 per cent granulated slag, 10-15 per cent hard burnt gypsum, and about 5 per cent Portland cement clinker. The product is ground finer than that of Portland cement. Specific surface must not be less than 4000 cm^2 per gm. The super-sulphated cement is extensively used in Belgium, where it is known as “ciment metallurgique sursulfate.” In France, it is known as “ciment sursulfate”.

This cement is rather more sensitive to deterioration during storage than Portland cement. Super-sulphated cement has a low heat of hydration of about 40-45 calories/gm at 7 days and 45-50 at 28 days. This cement has high sulphate resistance. Because of this property this cement is particularly recommended for use in foundation, where chemically aggressive conditions exist. As super-sulphated cement has more resistance than Portland blast furnace slag cement to attack by sea water, it is also used in the marine works. Other areas where super-sulphated cement is recommended include the fabrication of reinforced concrete pipes which are likely to be buried in sulphate bearing soils. The substitution of granulated slag is responsible for better resistance to sulphate attack.

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9) Portland Pozzolana Cement (IS 1489–1991)

The history of pozzolanic material goes back to Roman's time. The descriptions and details of pozzolanic material will be dealt separately under the chapter 'Admixtures'. However a brief description is given below.

Portland Pozzolana cement (PPC) is manufactured by the intergrinding of OPC clinker with 10 to 25 per cent of pozzolanic material (as per the latest amendment, it is 15 to 35%). A pozzolanic material is essentially a silicious or aluminous material which while in itself possessing no cementitious properties, which will, in finely divided form and in the presence of water, react with calcium hydroxide, liberated in the hydration process, at ordinary temperature, to form compounds possessing cementitious properties. The pozzolanic materials generally used for manufacture of PPC are calcined clay (IS 1489 part 2 of 1991) or fly ash (IS 1489 part I of 1991). Fly ash is a waste material, generated in the thermal power station, when powdered coal is used as a fuel. These are collected in the electrostatic precipitator.

❖ **Testing of cement**

Testing of cement can be brought under two categories:

(a) Field testing

(b) Laboratory testing.

Field testing

It is sufficient to subject the cement to field tests when it is used for minor works. The following are the field tests:

(a) Open the bag and take a good look at the cement. There should not be any visible lumps. The colour of the cement should normally be greenish grey.

(b) Thrust your hand into the cement bag. It must give you a cool feeling. There should not be any lump inside.

(c) Take a pinch of cement and feel-between the fingers. It should give a smooth and not a gritty feeling.

(d) Take a handful of cement and throw it on a bucket full of water, the particles should float for some time before they sink.

(e) Take about 100 grams of cement and a small quantity of water and make a stiff paste. From the stiff paste, pat a cake with sharp edges. Put it on a glass plate and slowly take it under water in a bucket. See that the shape of the cake is not disturbed while taking it down to the bottom of the bucket. After 24 hours the cake should retain its original shape and at the same time it should also set and attain some strength.

If a sample of cement satisfies the above field tests it may be concluded that the cement is not bad. The above tests do not really indicate that the cement is really good for important works. For using cement in important and major works it is incumbent on the part of the user to test the cement in the laboratory to confirm the requirements of the Indian Standard specifications with respect to its physical and chemical properties. No doubt, such confirmations will have been done at the factory laboratory before the production comes out from the factory. But the cement may go bad during transportation and storage prior to its use in works. The following tests are usually conducted in the laboratory.

(a) Fineness test. (*b*) Setting time test.

(*c*) Strength test. (*d*) Soundness test.

(e) Heat of hydration test. (*f*) Chemical composition test.

❖ Hydration of cement

The setting and hardening of concrete are the result of chemical and physical processes that take place between Portland cement and water, i.e. hydration. To understand the properties and behaviour of cement and concrete some knowledge of the chemistry of hydration is necessary.

A) Hydration reactions of pure cement compounds

The chemical reactions describing the hydration of the cement are complex. One approach is to study the hydration of the individual compounds separately. This assumes that the hydration of each compound takes place independently of the others.

I. Calcium silicates

Hydration of the two calcium silicates gives similar chemical products, differing only in the amount of calcium hydroxide formed, the heat released, and reaction rate.

$2\ C3S + 7\ H \rightarrow C3S2H4 + 3\ CH\ 2\ C2S + 5\ H \rightarrow C3S2H4 + CH$

The principal hydration product is C3S2H4, calcium silicate hydrate, or C-S-H (non-stoichiometric). This product is not a well-defined compound. The formula C3S2H4 is only an approximate description. It has amorphous structure making up of poorly organized layers and is called glue gel binder. C-S-H is believed to be the material governing concrete strength. Another product is CH - Ca(OH)2, calcium hydroxide. This product is a hexagonal crystal often forming stacks of plates. CH can bring the pH value to over 12 and it is good for corrosion protection of steel.

II. Tricalcium aluminate

Without gypsum, C3A reacts very rapidly with water:

$C3A + 6\ H \rightarrow C3AH6$

The reaction is so fast that it results in flash set, which is the immediate stiffening after mixing, making proper placing, compacting and finishing impossible.

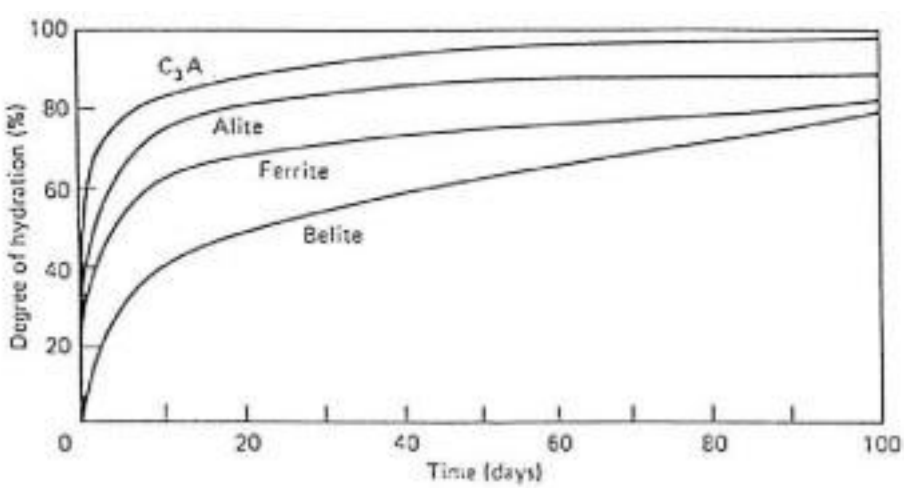
With gypsum, the primary initial reaction of C3A with water is :

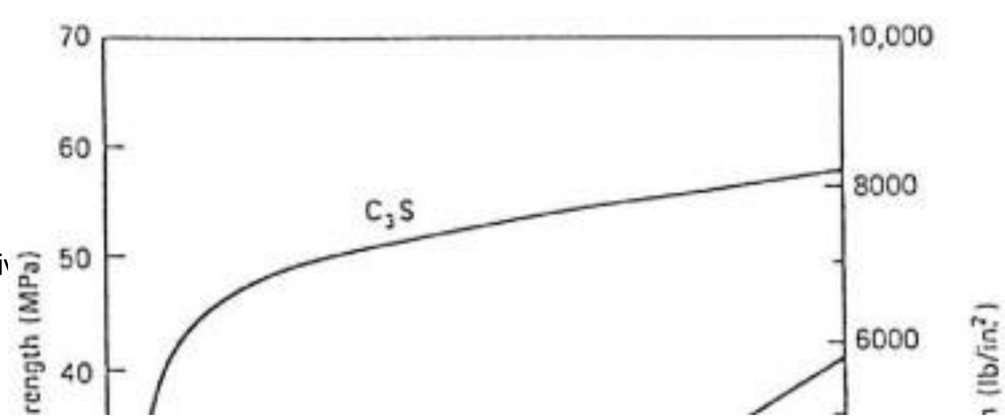
$C3A + 3\ (C\ S\ H2) + 26\ H \rightarrow C6A\ S\ 3H32$

The 6-calcium aluminate trisulfate-32-hydrate is usually called ettringite. The formation of ettringite slows down the hydration of C3A by creating a diffusion barrier around C3A. Flash set is thus avoided. Even with gypsum, the formation of ettringite occurs faster than the hydration of the calcium silicates. It therefore contributes to the initial stiffening, setting and early strength development. In normal cement mixers, the ettringite is not stable and will further react to form monosulphate (*C4A S H18).*

B) Kinetics and Reactivities

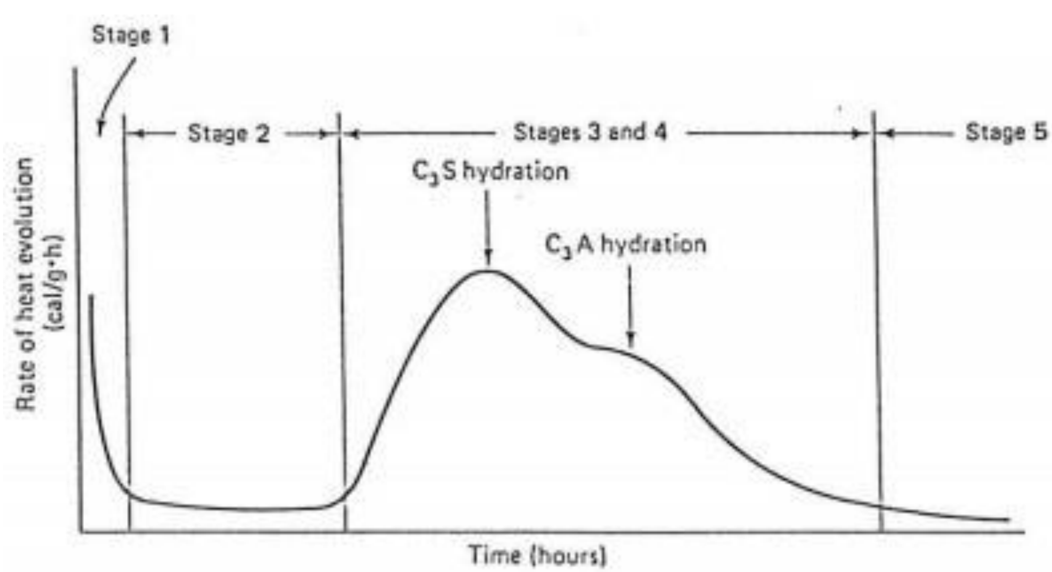
The rate of hydration during the first few days is in the order of C3A > C3S > C4AF >C2S.





Calorimetric curve of Portland cement

A typical calorimetric curve of Portland cement is shown in the following figure. The second heat peaks of both C3S and C3A can generally be distinguished, although their order of occurrence can be reversed.



From the figure, five stages can be easily identified. Since C3S is a dominating component in cement, the five stages above can be explained using the reaction process of C3S by the following table.

Reaction Stage	Kinetics of Reaction	Chemical Processes	Relevance to Concrete
1. Initial hydrolysis	Chemical control; rapid	Initial hydrolysis; dissolution of ions	
2. Induction period	Nucleation control; slow	Continued dissolution of ions	Determines initial set
3. Acceleration	Chemical control: rapid	Initial formation of hydration products	Determines final set and rate of initial hardening
4. Deceleration	Chemical and diffusion control; slow	Continued formation of hydration products	Determines rate of early strength gain
5. Steady State	Diffusion control; slow	Slow formation of hydration products	Determines rate of later strength gain

On first contact with water, calcium ions and hydroxide ions are rapidly released from the surface of each C3S grain; the pH values rises to over 12 within a few minutes. This hydrolysis slows down quickly but continues throughout the induction period. The induction (dormant) period is caused by the need to achieve a certain concentration of ions in solution before crystal nuclei are formed for the hydration products to grow from. At the end of dormant period, CH starts to crystallize from solution with the concomitant formation of C-S-H and the reaction of C3S again proceeds rapidly (the third stage begin). CH crystallizes from solution, while C-S-H develops from the surface of C3S and forms a coating covering the grain. As hydration continues, the thickness of the hydrate layer increases and forms a barrier through which water must flow to reach the un hydrated C3S and through which ions must diffuse to reach the growing crystals. Eventually, movement through the C-S-H layer determines the rate of reaction. The process becomes diffusion controlled.

D) Setting and Hydration

Initial set of cement corresponds closely to the end of the induction period, 2-4 hours after mixing. Initial set indicates the beginning of forming of gel or beginning of solidification. It represents approximately the time at which fresh concrete can no longer be properly mixed, placed or compacted. The final set occurs 5-10 hours after mixing, within the acceleration period. It represents approximately the time after which strength develops at a significant rate.

In practice, initial and final set are determined in a rather arbitrary manner with the penetration test. While the determination of initial and the final set has engineering significance, there is no fundamental change in hydration process for these two different set conditions.

❖ Types of Portland cements

According to ASTM standard, there are five basic types of Portland cement.

Type I Regular cement, general use, called OPC

Type II Moderate sulphate resistance, moderate heat of hydration, C3A < 7%

Type III With increased amount of C3S, High early strength

Type IV Low heat

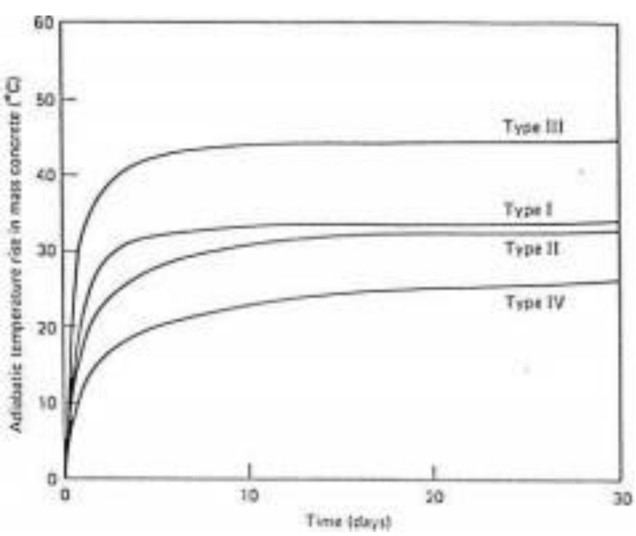
Type V High sulphate resistance

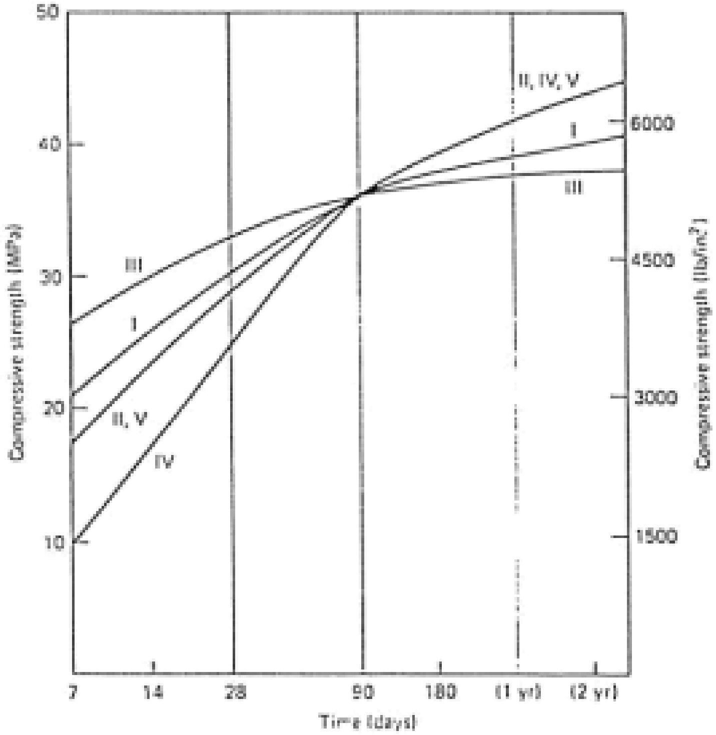
(Note: sulphates can react with *C4A S H18* to from an expansive product. By reducing the C3A content, there will be less *C4A S H18* formed in the hardened paste)

Their typical chemical composition is given in the following table:

	I	II	III	IV	V
C_3S	50	45	60	25	40
C_2S	25	30	15	50	40
C_3A	12	7	10	5	4
C_4AF	8	12	8	12	10
$C\bar{S}H_2$	5	5	5	4	4
Fineness (Blaine, m^2/kg)	350	350	450	300	350
Compressive strength at 1 day, MPa (psi)	7 (1,000)	6 (900)	14 (2,000)	3 (450)	6 (900)
Heat of hydration (7 days, J/g)	330	250	500	210	250

From the above table, we can evaluate the behaviour of each type of cement and provide the standard in selecting different cement types. The following figures show the strength and temperature rise for the different types of cement.





These graphs provide the basic justification in selecting the cement for engineering application. For instance, for massive concrete structure, hydration heat is an important consideration because excessive temperature increase (to above 50-60^{o}C) will cause expansion and cracking. Hence, type IV cement should be the first candidate and Type III should not be used. For a foundation exposed to groundwater with high concentration of sulphates, high sulphate resistance is needed. Thus, type V should be selected. If high early strength is needed, type III will be the best choice. But, generally, type I is the most popular cement used for civil engineering.

Porosity of hardened cement paste and the role of water

Knowledge of porosity is very useful since porosity has a strong influence on strength and durability. In hardened cement paste, there are several types of porosity, trapped or entrained air (0.1 to several mm in size), capillary pores (0.01 to a few microns) existing in the space between hydration products, and gel pores (several nanometres or below) within the layered structure of the C-S-H. The capillary pores have a large effect on the strength and permeability of the hardened paste itself. Of course, the presence of air bubbles can also affect strength.

From experiments, the porosity within the gel for all normally hydrated cements is the same, with a value of 0.26. The total volume of hydration products (cement gel) is given by

$$V_g = 0.68\alpha \text{ cm}^3/\text{g of original cement}$$

Where, α represents the degree of hydration.

The capillary porosity can be calculated by

$$P_c = (w/c) - 0.36\alpha \text{ cm}^3/\text{g of original cement}$$

Where, *w* is the original weight of water and *c* is the weight of cement and w/c is the water-cement ratio. It can be seen that with increase of w/c, the capillary pores increase.

The gel / space ratio (X) is defined as

$$X = \frac{\text{volume of gel (including gel pores)}}{\text{volume of gel + volume of capillary pores}}$$

$$= \frac{0.68\alpha}{0.32\alpha + w/c}$$

The minimum w/c ratio for complete hydration is usually assumed to be 0.36 to 0.42. It should be indicated that complete hydration is not essential to attain a high ultimate strength. For pastes of low w/c ratio, residual unhydrated cement will remain.

To satisfy workability requirements, the water added in the mix is usually more than that needed for the chemical reaction. Part of the water is used up in the chemical reaction. The remaining is either held by the C -S-H gel or stored in the capillary pore. Most capillary water is free water (far away from the pore surface). On drying, they will be removed, but the loss of free water has little effect on concrete. Loss of adsorbed water on surfaces and those in the gel will, however, lead to shrinkage. Movement of adsorbed and gel water under load is a cause of creeping in concrete

❖ Basic tests of Portland cement

a) Fineness (= surface area / weight): This test determines the average size of cement grains. The typical value of fineness is 350 m^2/ kg.

Fineness controls the rate and completeness of hydration. The finer a cement, the more rapidly it reacts, the higher the rate of heat evolution and the higher the early strength.

Fineness (m^2/ kg) 350 450 350

f'c 1-day (MPa) 6.9 13.8 6.2

b) Normal consistency test: This test is to determine the water required to achieve a desired plasticity state (called normal consistency) of cement paste. It is obtained with the Vicat apparatus by measuring the penetration of a loaded needle.

c) Time of setting: This test is to determine the time required for cement paste to harden. Initial set cannot be too early due to the requirement of mixing, conveying, placing and casting. Final set cannot be too late owing to the requirement of strength development. Time of setting is measured by Vicat apparatus. Initial setting time is defined as the time at which the needle penetrates 25 mm into cement paste. Finalsetting time is the time at which the needle does not sink visibly into the cement paste.

d) Soundness: Unsoundness in cement paste refers to excessive volume change after setting. Unsoundness in cement is caused by the slow hydration of MgO or free lime. Their reactions are MgO +H2O = Mg(OH)2 and CaO + H2O = Ca(OH)2. Another factor that can cause unsoundness is the delayed formation of ettringite after cement and concrete have hardened. The pressure from crystal growth will lead to cracking and damage. The soundness of the cement must be tested by accelerated methods. An example is the Le Chatelier test (BS 4550). This test is to measure the potential for volumetric change of cement paste. Another method is called Autoclave Expansion test (ASTM C151) which use an autoclave to increase the temperature to accelerate the process.

e) Strength: The strength of cement is measured on mortar specimens made of cement and standard sand (silica). Compression test is carried out on a 2" cube with S/C ratio of 2.75:1 and w/c ratio of 0.485 for Portland cements. The specimens are tested wet, using a loading rate at which the specimen will fail in 20 to 80 s. The direct tensile test is carried out on a specimen shaped like a dumbbell. The load is applied through specifically designed grips. Flexural strength is measured on a 40 x 40 x 160 mm prism beam test under a centre-point bending.

f) Heat of hydration test. (BS 4550: Part 3: Section 3.8 and ASTM C186). Cement hydration is a heat releasing process. The heat of hydration is usually defined as the amount of heat evolved during the setting and hardening at a given temperature measured in J/g. The experiment is called heat of solution method. Basically, the heat of solution of dry cement is compared to the heats of solution of separate portion of the cement that have been partially hydrated for 7 and 28 days. The heat of hydration is then the difference between the heats of solution of dry and partially hydrated cements for the appropriate hydration period. This test is usually done on Type II and IV cements only, because they are used when heat of hydration is an important concern. Excessive heating may lead to cracking in massive concrete construction.

g) Other experiments. Including sulphate expansion and air content of mortar.

h) Cement S. G and U. W.: The S.G. for most types of cements is 3.15, and UW is 1000-1600 kg/m^3.

❖ 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.

❖ Admixtures can be classified by function as follows:

1. Air-entraining admixtures
2. Water-reducing admixtures
3. Plasticizers
4. Accelerating admixtures
5. Retarding admixtures
6. Hydration-control admixtures
7. Corrosion inhibitors
8. Shrinkage reducers
9. Alkali-silica reactivity inhibitors
10. Colouring admixtures
11. Miscellaneous admixtures such as workability, bonding, dampproofing, permeability reducing, grouting, gas forming, anti-washout, foaming, and pumping admixtures.

Concrete should be workable, finishable, strong, durable, watertight, and wear resistant. These qualities can often be obtained easily and economically by the selection of suitable materials rather than by resorting to admixtures (except air-entraining admixtures when needed).

The major reasons for using admixtures

1. To reduce the cost of concrete construction
2. To achieve certain properties in concrete more effectively than by other means
3. To maintain the quality of concrete during the stages of mixing, transporting, placing, and curing in adverse weather conditions
4. To overcome certain emergencies during concreting operations

❖ Aggregates

Aggregates are defined as inert, granular, and inorganic materials that normally consist of stone or stone like solids. Aggregates can be used alone (in road bases and various types of fill) or can be used with cementing materials (such as Portland cement or asphalt cement) to form composite materials or concrete. The most popular use of aggregates is to form Portland cement concrete. Approximately three-fourths of the volume of Portland cement concrete is occupied by aggregate. It is inevitable that a constituent occupying such a large percentage of the mass should have an important effect on the properties of both the fresh and hardened products. As another important application, aggregates are used in asphalt cement concrete in which they occupy 90% or more of the total volume. Once again, aggregates can largely influence the composite properties due to its large volume fraction.

❖ Classification of Aggregate

Aggregates can be divided into several categories according to different criteria.

a) In accordance with size:

Coarse aggregate: Aggregates predominately retained on the No. 4 (4.75 mm) sieve. For mass concrete, the maximum size can be as large as 150 mm.

Fine aggregate (sand): Aggregates passing No.4 (4.75 mm) sieve and predominately retained on the No. 200 (75 μm) sieve.

b) In accordance with sources:

Natural aggregates: This kind of aggregate is taken from natural deposits without changing their nature during the process of production such as crushing and grinding. Some examples in this category are sand, crushed limestone, and gravel.

Manufactured (synthetic) aggregates: This is a kind of man-made materials produced as a main product or an industrial by-product. Some examples are blast furnace slag, lightweight aggregate (e.g. expanded perlite), and heavy weight aggregates (e.g. iron ore or crushed steel).

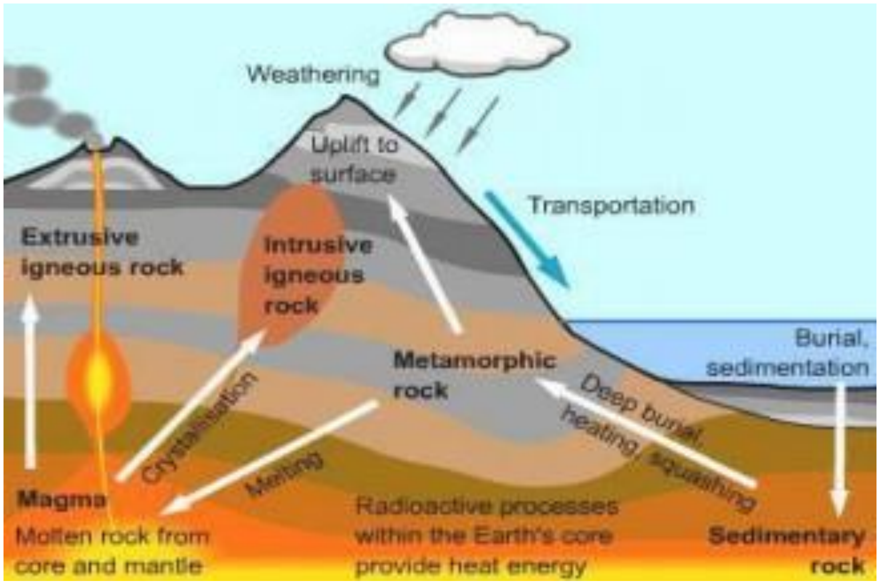
c) In accordance with unit weight:

Light weight aggregate: The unit weight of aggregate is less than 1120kg/m^3. The corresponding concrete has a bulk density less than 1800kg/m^3. (cinder, blast-furnace slag, volcanic pumice).

Normal weight aggregate: The aggregate has unit weight of 1520-1680kg/m^3. The concrete made with this type of aggregate has a bulk density of 2300-2400 kg/m^3.

Heavy weight aggregate: The unit weight is greater than 2100 kg/m^3. The bulk density of the corresponding concrete is greater than 3200 kg/m^3. A typical example is magnesite limonite, a heavy iron ore. Heavy weight concrete is used in special structures such as radiation shields.

d) In accordance with origin:



Igneous rock Aggregate:

- Hard, tough and dense.
- Massive structures: crystalline, glassy or both depending on the rate at which they are cooled during formation.
- Acidic or basic: percentage of silica content.
- Light or dark coloured.
- Chemically active: react with alkalis.

e) **Classification of Aggregates as per Size and Shape**

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

f) **Classification of Aggregates Based on Shape**

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.

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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.

g) Classification of Aggregates Based on Size

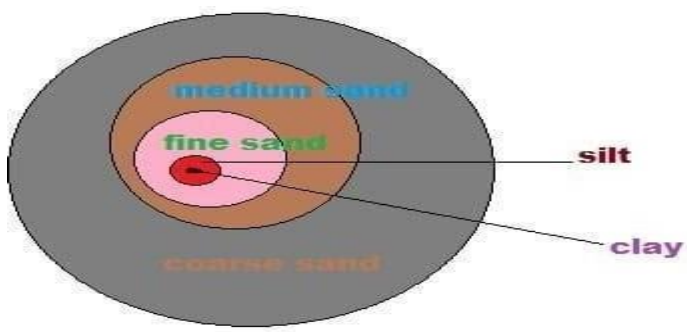
Aggregates are available in nature in different sizes. The size of aggregate used may be related to the mix proportions, type of work etc. the size distribution of aggregates is called grading of aggregates. Following are the classification of aggregates based on size: Aggregates are classified into 2 types according to size

- Fine aggregate
- Coarse aggregate

When the aggregate is sieved through 4.75mm sieve, the aggregate passed through it called as fine aggregate. Natural sand is generally used as fine aggregate, silt and clay are also come under this category. The soft deposit consisting of sand, silt and clay is termed as loam. The purpose of the fine aggregate is to fill the voids in the coarse aggregate and to act as a workability agent.

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

When the aggregate is sieved through 4.75mm sieve, the aggregate retained is called coarse aggregate. Gravel, cobble and boulders come under this category. The maximum size aggregate used may be dependent upon some conditions. In general, 40mm size aggregate used for normal strengths and 20mm size is used for high strength concrete. 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

g) Angularity number (IS: 2386-Part 1-1963):

- The concept of angularity number was suggested by Shergold.
- It gives a qualitative representation of shape of aggregate.
- In angularity number test, a quantity of single sized aggregate is filled into metal cylinder of 3 litres capacity. Then the aggregate is compacted in a standard manner and the percentage of void found out.
- If the void content of the aggregate is 33% the angularity of such aggregate is considered 0. If the void is 44%, the angularity number of such aggregate is considered 11.

h) Texture:

- It depends on hardness, grain size, pore structure, structure of the rock and degree to which forces acting on the particle surface have smoothened or roughened it.
- As surface smoothness increases, contact area decreases, hence a highly polished particle will have less bonding area with the matrix than a rough particle of the same volume.

❖ Strength of Aggregates

• When the cement paste is of good quality & its bond with the aggregate is satisfactory, then the mechanical properties of rock or aggregate will influence the strength of concrete.

• The test for strength of aggregate is required to be made in the following situations:

i. For production of high strength & ultra -high strength concrete.

ii. When contemplating to use aggregates manufacture from weathered rocks.

iii. Aggregates manufactured by industrial process.

❖ Physical properties of aggregates:

1) Size and shape:

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 bar
- Remember that the size & shape of aggregate particles influence the properties of freshly mixed concrete more as compared to those of hardened concrete.

2) Composition:

Aggregates consisting of materials that can react with alkalies in cement and cause excessive expansion, cracking and deterioration of concrete mix should never be used. Therefore it is required to test aggregates to know whether there is presence of any such constituents in aggregate or not.

3) 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.

3) Specific gravity

The ratio of weight of oven dried aggregates maintained for 24 hours at a temperature of 100 to 1100C, 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.

- Apparent specific gravity
- 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 2.6 to 2.9. Specific gravity values are also used while designing concrete mix.

4). 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.

Bulk density of aggregates depends upon the following 3 factors.

- Degree of compaction
- Grading of aggregates
- Shape of aggregate particles

5) 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.

6) Porosity and 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)

7) 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.

8) Surface of Aggregate

The surface area per unit weight of the material is termed as specific surface. This is an indirect measure of the aggregate grading. Specific surface increases with the reduction in the size of aggregate particle. The specific surface area of the fine aggregate is very much more than that of coarse aggregate.

❖ **<u>Mechanical Properties of Aggregates</u>:**

Toughness:

- It is defined as the resistance of aggregate to failure by impact. The impact value of bulk aggregate can be determined as per I.S. 2386, 1963.The test procedure is as follows :
- The aggregate shall be taken as in the case of crushing strength value test i.e., the aggregate should pass through 12.5 mm I.S. sieve and retained on 10 mm I.S. sieve. It should be oven dried at 100°C to 110°C for four hours and then air cooled before test.
- Now the prepared aggregate is filled upto 1/3rd height of the cylindrical cup of the equipment. The diameter and depth of the cup are 102 mm and 50 mm respectively. After filling the cup upto 1/3rd of its height, the aggregate is tamped with 25 strokes of the rounded end of the tamping rod.
- After this operation the cup shall be further filled upto 2/3rd of its height and a further tamping of 25 strokes given. The cup finally shall be filled to over flowing and tamped with 25 strokes and surplus aggregate removed and the weight of aggregate noted. The value of weight will be useful to repeat the experiment.
- Now the hammer of the equipment weighting 14.0 kg or 13.5 kg is raised till its lower face is 380 mm above the upper surface of the aggregate and., allowed to fall freely on the aggregate and the process is repeated for 15 times.
- The crushed aggregate is now removed from the cup and sieved through 2.36 mm I.S. sieve. The fraction passing through the sieve is weighed

accurately.

Let the weight of oven dry sample in the cup = W kg.

Weight of aggregate passing 2.36 mm sieve = W1 kg.

Then impact value = [(W1/W) x 100

Hardness:

It is defined as the resistance to wear by abrasion, and the aggregate abrasion value is defined as the percentage loss in weight on abrasion.

For testing hardness of aggregate following three methods can be used:

(a) Deval Attrition test.

(b) Dorry abrasion test.

(c) Los Angeles test.

(a) Deval Attrition Test:

This test has been covered by IS 2386 Part (IV)-1963. In this test particles of known weight are subjected to wear in an iron cylinder rotated 10,000 (ten thousand) times at the rate of 30 to 33 revolutions per minute. After the specified revolution of the cylinder the material is taken out and sieved on 1.7 mm sieve and the percentage of material finer than 1.7mm is determined. This percentage is taken as the attrition value of the aggregate. The attrition value of about 7 to 8 usually is considered as permissible.

(b) Dorry Abrasion Test:

This test has not been covered by Indian standard specifications. In this test a cylindrical specimen having its diameter and height of 25 cm is subjected to abrasion against a rotating metal disk sprinkled with quartz sand. The loss in weight of the cylinder after 1000 (one thousand) revolutions is determined.

Then the hardness of rock sample is expressed by an empirical relation as follows:

Hardness or sample = 20 – Loss in weight in grams/3

For good rock this value should not be less the 17. The rock having this value of 14 is considered poor.

(c) Los-Angeles Test:

This test has been covered by IS 2386 (Part-IV) 1963. In this test aggregate of the specified grading is placed in a cylindrical drum of inside length and diameter of 500 mm and 700 mm respectively. This cylinder is mounted horizontally on stub shafts. For abrasive charge, steel balls or cast iron balls of approximately 48 mm diameter and each weighting 390 grams to 445 gram are used. The numbers of balls used vary from 6 to 12 depending upon the grading of the aggregate. For 10 mm size aggregate 6 balls are used and for aggregates bigger than 20 mm size usually 12 balls are used.

Procedure:

For the conduct of test, the sample and the abrasive charge are placed in the Los-Angeles testing machine and it is rotated at a speed of 20 to 33 revolutions per minute. For aggregates upto 40 mm size the machine is rotated for 500 revolutions and for bigger size aggregate 1000 revolutions. The charge is taken out from the machine and sieved on 1.7 mm sieve.

Let the weight of oven dry sample put in the drum = W Kg.

Weight of aggregate passing through 1.7 sieve = W1 Kg.

Then abrasion value = [(W1/W) x 100]

The abrasion value should not be more than 30% for wearing surfaces and not more than 50% for concrete used for other than wearing surface. The results of Los Angeles test show good correlation not only the actual wear of aggregate when used in concrete, but also with the compression and flexural strength of concrete made with the given aggregate.

Specific Gravity:

The specific gravity of a substance is the ratio of the weight of unit volume of the substance to the unit volume of water at the stated temp. In concrete making, aggregates generally contain pores both permeable and impermeable hence the term specific gravity has to be defined carefully. Actually there are several types of specific gravity. In concrete technology specific gravity is used for the calculation of quantities of ingredients. Usually the specific gravity of most aggregates varies between 2.6 and 2.8.

Method of Determination of Specific Gravity of Aggregate:

IS-2386-Part-III-1963 describes various procedures to find out the specific gravity of aggregates of different sizes. Here the method applicable to aggregates larger than 10 mm in size has been described as follows —

A sample of aggregate not less than 2 kg in weight is taken and washed thoroughly to remove dust, and silt particles etc. The washed sample is placed in a wire basket and immersed in distilled water at a temperature of 27 ± 5°C.

Immediately after immersion, the entrapped air is removed from the sample by lifting the basket containing sample 25 mm above the bottom of the jar or tank and allow it drop 25 times at the rate of 1 mm per sec. During this operation, care should be taken that basket and aggregate remain fully immersed in water. After this, the sample is kept in water for about 24 ± ½ hour.

After this period the basket and aggregate is given a jerk to remove the air etc. and weighed in water at the temperature of 27 ± 5°C. Let the weight of basket and aggregate be A1. The basket and sample of aggregate is removed from the water and allowed to drain for a few minutes. Then the aggregate is taken out from the basket and placed on a dry cloth and dried further. The empty basket is again immersed in water and weighed in water after giving 25 jolts. Let this weight be A2.

The aggregate is surface dried in shade for not more than 10 minutes and the aggregate is weighed in air. Let this weight be B. Now the aggregate is oven dried for 24 ± ½ hour at a temperature of 100 to 110°C. It is then cooled in air tight container and weighed. Let this weight be C.

Thus,

Weight of sample in water = (A1 – A2) = A

Weight of saturated surface dry in air sample = B

Weight of oven dry sample = C

(a) Then specific gravity = [C/(B – A)]

(b) Apparent specific gravity = [C/(C – A)]

(c) Water absorption = 100 (B – C)

(d) Bulk density = Net weight of the aggregate in kg./capacity or the container in litres.

❖ **Deleterious substance in aggregate**

Deleterious materials in aggregate are those substances which detrimentally effect the fresh and hardened properties of concrete for instance strength, workability, and long-term performance of the concrete in which such are used. Deleterious materials and highly undesirable constituents.

There are tests such as colorimetric test recommended by ASTM C 40-92 which are used to determine aggregate organic content. The colorimetric test does not show the adverse effect of deleterious materials in aggregate. This is because high aggregate deleterious substance content does not infer that the aggregate is not fit for utilization that is why strength test based on ASTM C 87-90 is recommended for mortars with questionable sand.

1) Organic impurities.

- Organic impurities interfere with the hydration reaction.
- Frequently, it is found in sand and consists of products of decay of vegetable matter.
- Organic matter may be removed from sand by washing.
- Colorimetric test recommended by ASTM C 40-92 can be used to determine aggregate organic content.
- The colorimetric test does not show the adverse effect of the organic impurity since high organic content does not necessarily mean that the aggregate is not fit for use in concrete.

- For this reason, strength test on mortar with questionable sand as per ASTM C 87-90 is recommended.

2) Clay

- Clay may coat the surface of aggregates which impair bond strength between aggregate and cement paste. Consequently, it adversely affecting the strength and durability of concrete
- It is necessary to control the amount of clay in aggregate
- Since no test is available to determine separately the clay content, the limits of fine materials are prescribed in terms of the percentage of material passing sieve No. 200.

3) Silt and Crusher dust:

- Silt and dust, owing to their fineness, increase the surface area and therefore increase the amount of water necessary to wet all the particles in the mix.
- Impair wear resistance
- Reduce durability
- They may result popouts
- It is necessary to control the amount of silt and fine dust in aggregate.
- Since no test is available to determine separately the silt and dust, the limits of fine materials are prescribed in terms of the percentage of material passing sieve No. 200

4) Salts:

- Salts are present in certain types of aggregates such as Sand from seashore, sand and Coarse aggregate dredged from the sea or a river estuary, and desert sand.
- Salts coming through aggregates cause reinforcement corrosion and also absorb moisture from the air and cause efflorescence.

- The BS 882:1992 limits on the chloride ion content of aggregate by mass, expressed as a percentage of the mass of total aggregate.

5) Unsound Particles

- Two major classes of unsound particles are materials fail to maintain their integrity, and substances lead to disruptive expansion on freezing or even on exposure to water
- Shale, particles with low density, clay lumps, wood, coal, mica, gypsum, and iron pyrites are examples of unsound particles.
- Unsound particles if present in large quantities (over 2 to 5% of the mass of the aggregate) may adversely affect the strength of concrete.
- These materials should not be allowed in concrete which is exposed to abrasion.
- Mica is very effective in reducing strength (15% reduction in 28-d f'c with 5% mica).
- Gypsum and iron pyrites are mainly responsible for expansion of concrete.

❖ Alkali Aggregate Reaction

Alkali aggregate reactions (AAR) occur when aggregates in concrete react with the alkali hydroxides in concrete producing a hygroscopic gel which, in the presence of moisture, absorbs water and causes expansion and cracking over a period of many years. This alkali-aggregate reaction has two forms, namely: **Alkali-silica reaction** (ASR) and **Alkali-carbonate reaction** (ACR).

The former is of higher concern since aggregates containing various forms of silica materials are very common whereas the latter occurs rarely because of the unsuitability of carbonates for use in concrete.

Nonetheless, concrete deterioration caused by each type of alkali-aggregate reaction is similar. It should be known that **no structure has ever collapsed due to alkali-aggregate**

reactions, but there are cases in which structural concrete members demolished due to the effect of alkali-aggregate reactions.

Most of the structures severely cracked by AAR are exposed to the weather or are in contact with damp soil. This is because- for a significant amount of expansion to occur, sufficient presence of moisture is essential. Apart from moisture, high content of alkali in the concrete is also essential.

Types of Alkali Aggregate Reaction:

1) Alkali-silica reaction (ASR)

- Random map cracking and closed joints and attendant spalling concrete are indicators of alkali-silica reactions.
- Petrographic examination can identify alkali-silica reactions.
- It occurs broadly because aggregates containing reactive silica materials are more common.
- Alkali-silica reaction generates enough expansive pressure to damage concrete.
- Lithium compounds can be used to decrease alkali-silica reactions.

2) Alkali-carbonate reaction (ACR)

- It is observed with certain dolomitic rocks.
- It may cause considerable expansion.
- Compare to alkali-silica reactions, ACR is fairly rare because aggregates susceptible to this phenomenon are less common.
- The use of supplementary cementing materials does not prevent deleterious expansion due to ACR.

Effects of Alkali Aggregate reaction:-

- Loss of strength, stiffness, impermeability.
- Affects concrete durability and appearance.
- Premature failure of concrete structures.
- Consequently, life of concrete structure is declined.
- Maintenance cost is increased.

Preventative Measures for AAR:-

- Use low alkali cement to limit alkali content in concrete
- Use of Cementitious Replacement Materials such as PFA and GGBS in concrete to decrease alkali content in concrete
- Reduce the access of moisture and maintain the concrete in a sufficiently dry state
- Avoid utilization of reactive aggregate otherwise necessary precautions shall be employed to prevent influences of alkali-aggregate reactions.
- Modify the properties of any gel such that it becomes non-expansive, for instance, using lithium salts.

❖ Thermal Properties of Aggregates

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

The principle thermal properties of aggregates are:

1) Coefficient of thermal expansion,
2) Specific heat
3) Thermal Conductivity

The coefficient of thermal expansion of the concrete increase with the coefficient of thermal expansion of aggregate. The coefficient of expansion of the aggregate depends on the parent rock.

The specific heat of aggregate is a measure of its heat capacity whereas, the thermal conductivity is the ability of the aggregate to conduct the heat.

❖ Sieve Analysis

A **sieve analysis** (or **gradation test**) is a practice or procedure used in civil engineering[1] and chemical engineering[2] to assess the particle size distribution (also called *gradation*) of a granular material by allowing the material to pass through a series of sieves of progressively smaller mesh size and weighing the amount of material that is stopped by each sieve as a fraction of the whole mass.

The size distribution is often of critical importance to the way the material performs in use. A sieve analysis can be performed on any type of non-organic or organic granular materials including sands, crushed rock, clays, granite, feldspars, coal, soil, a wide range of manufactured powders, grain and seeds, down to a minimum size depending on the exact method.

Sieve Analysis of Fine Aggregates:

Sieve analysis of fine aggregates is one of the most important tests performed on-site. Aggregates are inert materials that are mixed with binding materials such as cement or lime for the manufacturing of mortar or concrete. It is also used as fillers in mortar and concrete. Aggregates size varies from several inches to the size of the smallest grain of sand. The Aggregates(fine + coarse) generally occupy 60% to 75% of the concrete volume or 70% to 85% by mass and strongly influence the concrete's freshly mixed and hardened properties, mixture proportions, and economy. All Aggregates pass IS 4.75 mm sieve is classified as fine Aggregates.

All aggregate technicians use the sieve analysis (gradation test) to determines the gradation (the particle size distribution, by size, within a given sample) in order to determine compliance with design, production control requirements, and verification specifications. Used in conjunction with other tests, the sieve analysis is very good to control and quality acceptance tool.

Objective

The whole procedure of sieve analysis is to determine the particle size distribution of the fine aggregates and determine whether it is suitable to use in concrete mixing.

Test Equipment

A series of IS sieves

- 4.75 mm
- 2.36 mm
- 1.18 mm
- 600 mic
- 300 mic
- 150 mic
- 75 mic

- Shovel
- Weighing Balance
- Sieve shaker
- 1000g of F.A

Experimental Procedure for Sieve Analysis

a. Weighed the sample to exactly 1000g.
b. First of all, we have to clean all the sieves using a wire brush to be clear of aggregates stuck in some gaps.
c. Then we have to prepare the sieves onto the shaking machine from top to bottom, by the size from biggest (4,75mm) to smallest (0.075mm).
d. The sample is sieved by using the set of IS Sieves for 10 minutes.
e. After the sieving is done, the aggregates on each sieve are weighed individually.
f. Cumulative weight passing through each sieve is calculated as a percentage of the total sample weight.
g. The same procedure is followed for two more samples.

The formula for calculating the percentage retained and percentage passing:

$$Percent\ retained(\%) = \frac{Weight\ of\ material\ retained\ on\ sieve}{Total\ sample\ weight} \times 100$$

$$Percent\ passing = 100\% - Cumulative\ percent\ retained$$

IS : 383 - 1970

TABLE 4 FINE AGGREGATES
(*Clause* 4.3)

IS SIEVE DESIGNATION	PERCENTAGE 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

The percentage passing weight so obtained shall than be compared with the permissible values given in the IS 383. The standard table in IS code shows the permissible values of percentage passing for different grading zones i.e., Zone I, Zone II, Zone III, and Zone IV. The zone of the sand thus is determined by comparing the observed percentage passing values with the permissible values given in the IS 383.

Soundness of aggregate:-

Soundness is the percentage loss of material from an **aggregate** blend during the sodium or magnesium sulfate **soundness** test. This test, which is specified in ASTM C88 and AASHTO T104, estimates the resistance of **aggregate** to in-service weathering. It can be performed on both coarse and fine **aggregate.**

Soundness refers to the ability of aggregate to resist excessive changes in volume as a result of changes in physical conditions. These physical conditions that affect the soundness of aggregate are the freezing the thawing, variation in temperature, alternate wetting and drying under normal conditions and wetting and drying in salt water. Aggregates which are porous, weak and containing any undesirable extraneous matters undergo excessive volume change when subjected to the above conditions. Aggregates which undergo more than the specified amount of volume change is said to be unsound aggregates. If concrete is liable to be exposed to the action of frost, the coarse and fine aggregate which are going to be used should be subjected to soundness test.

The soundness test consists of alternative immersion of carefully graded and weighed test sample in a solution of sodium or magnesium sulphate and oven drying it under specified conditions. The accumulation and growth of salt crystals in the pores of the particles is thought to produce disruptive internal forces similar to the action of freezing of water or crystallisation of salt. Loss in weight, is measured for a specified number of cycles. Soundness test is specified in IS 2386 (Part V). As a general guide, it can be taken that the average loss of weight after 10 cycles should not exceed 12 per cent and 18 per cent when tested with sodium sulphate and magnesium sulphate respectively.

It may be pointed out that the sulphate soundness test might be used to accept aggregates but not to reject them, the assumption being that aggregates which will satisfactorily withstand the test are good while those which breakdown may or may not be bad. Unfortunately, the test is not reliable. Certain aggregates with extremely fine pore structure show almost no loss of weight. Conversely, certain aggregates that disintegrate readily in the sulphate test but produce concrete of high resistance to freezing and thawing. A low loss of weight usually. but not always, an evidence of good durability, whereas a high loss of weight places the aggregate in questionable category.

Grading curves:-

The **grading curve** graphically represents the proportion of different grain sizes which the **aggregate** is composed of and which form part of the shortcrete mix. It provides useful information to find out: Whether the distribution of the different **aggregate** sizes is suitable for pumping.

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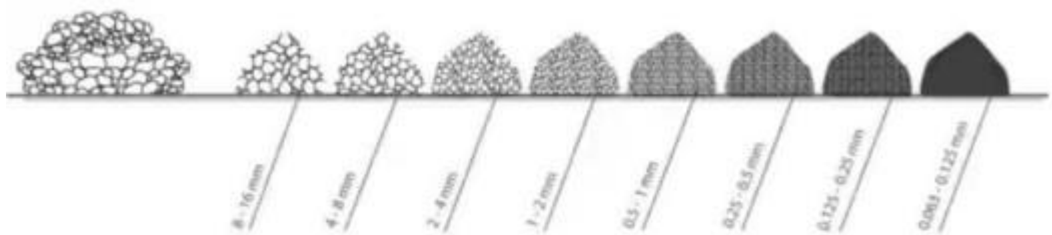
Whether the distribution of the different aggregate sizes is suitable for pumping

The fines content of the aggregates (particles with a diameter << 0,125 mm), which affects the properties of workability, internal adhesion and early strength development of the shortcrete mix.

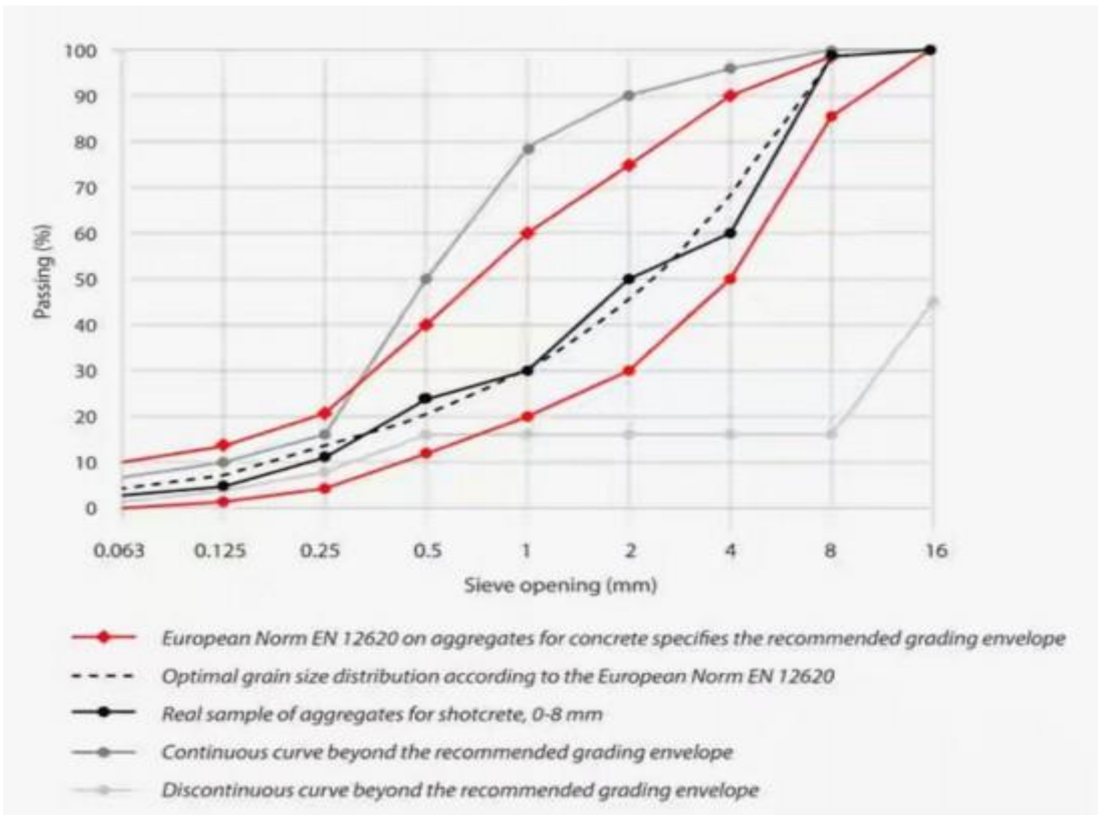
Screening test to separate the aggregate particles:-

The process to obtain the grading curve consists in passing the aggregate sample through a series of standardized sieves of different diameters mounted on a column. The aggregates are exposed to vibration and rotation movements in order to obtain the classification by size. Afterwards, the sieves are removed and the retained material in each one is weighed.



Different sizes of separated particles after the screening

Continuous and discontinuous grading curves



Continuous and discontinuous grading curves

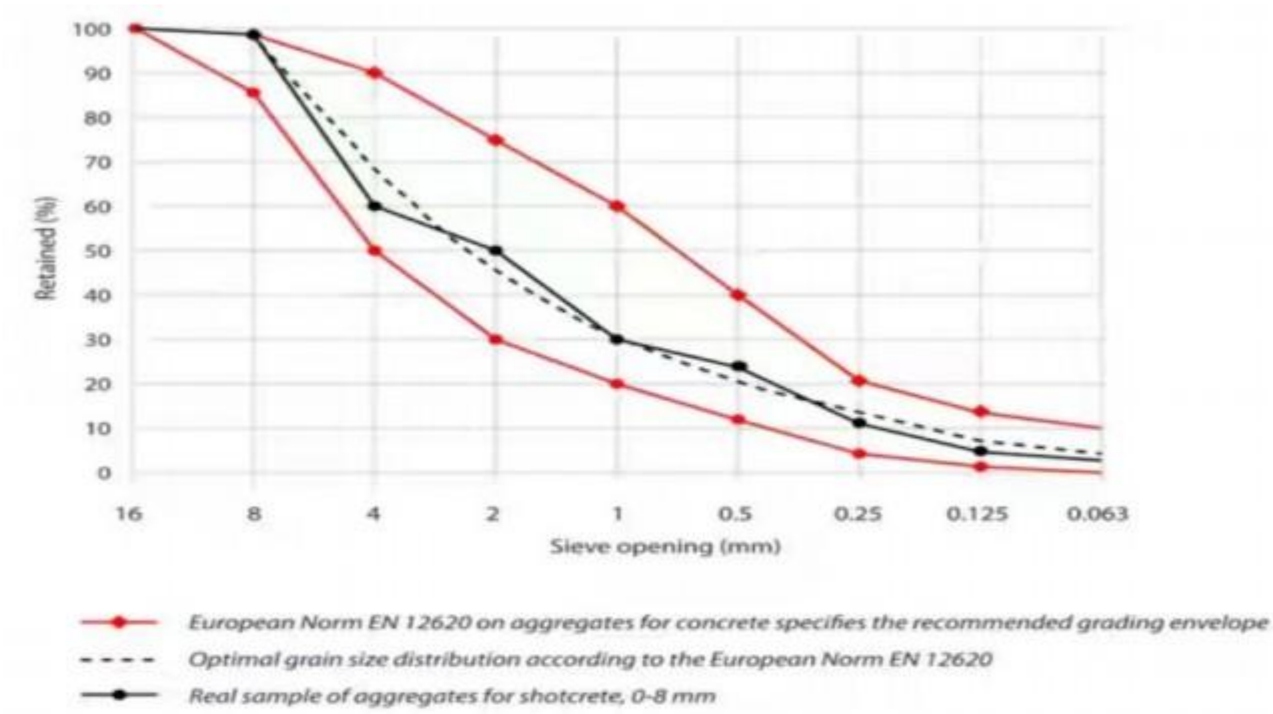
A continuous curve, in contrast to a discontinuous one, represents an aggregate composition with particles of all sizes.

- In the graphic, the black curve represents a continuous curve and within the grading envelope recommended by the norm, therefore the aggregate composition is adequate for the shortcrete mixture.

- The light gray curve represents the most unfavorable scenario: discontinuous and beyond what is recommended by the norm.

Passing and retaining grading curves:-

The difference consists in measuring the percentage of the aggregate which passes through the sieve, like in the latest examples (passing curves), or the percentage which is retained (retaining curve); in this case the curve is declining:



Pay special attention to the fines content

The fines content of the mixture is important to achieve a good a compression of the shortcrete mixture and to improve its workability.

Besides the fines in the aggregate, the total fine material of the shortcrete mix includes binder content, consisting of:

Cement

Additives (fly ash, silica fume, etc)

The recommended fines content of the mixture lies between 450 and 500 kg/m3, thus if there is a lack of fines in the aggregate, it should be compensated with binder content.

❖ Measurement of Surface Texture:-

A large number of possible methods are available and this may be divided broadly into direct and indirect methods. Direct methods include (*i*) making a cast of the surface and magnifying a section of this, (*ii*) Tracing the irregularities by drawing a fine point over the surface and drawing a trace magnified by mechanical, optical, or electrical means, (*iii*) getting a section through the aggregates and examining a magnified image. Indirect methods include: (*i*) measurement of the degree of dispersion of light falling on the surface, (*ii*) determining the weight of a fine powder required to fill up the interstices of the surface to a truly smooth surface, (*iii*) the rock surface is held against rubber surface at a standard pressure and the resistance to the flow of air between the two surfaces is measured.

Aggregate Crushing Value

Strength of rock is found out by making a test specimen of cylindrical shape of size 25 mm diameter and 25 mm height. This cylinder is subjected to compressive stress. Different rock samples are found to give different compressive strength varying from a minimum of about 45 MPa to a maximum of 545 MPa. As said earlier, the compressive strength of parent rock does not exactly indicate the strength of aggregate in concrete. For this reason assessment of strength of the aggregate is made by using a sample of bulk aggregate in a standardised manner. This test is known as aggregate crushing value test. Aggregate crushing value gives a relative measure of the resistance of an aggregate sample to crushing under gradually applied compressive load. Generally, this test is made on single sized aggregate passing

12.5 mm and retained on 10 mm sieve. The aggregate is placed in a cylindrical mould and a load of 40 ton is applied through a plunger. The material crushed to finer than 2.36 mm is separated and expressed as a percentage of the original weight taken in the mould. This percentage is referred as aggregate crushing value. The crushing value of aggregate is restricted to 30 per cent for concrete used for roads and pavements and 45 per cent may be permitted for other structures.

The crushing value of aggregate is rather insensitive to the variation in strength of weaker aggregate. This is so because having been crushed before the application of the full load of 40 tons, the weaker materials become compacted, so that the amount of crushing during later stages of the test is reduced. For this reason a simple test known as "10 per cent fines value" is introduced. When the aggregate crushing value become 30 or higher, the result is likely to be inaccurate, in which case the aggregate should be subjected to "10 per cent fines value" test which gives a better picture about the strength of such aggregates.

Aggregate Impact Value Apparatus

This test is also done on a single sized aggregate as mentioned above. Load required to produce 10 per cent fines (particles finer than 2.36 mm) is found out by observing the penetration of plunger. The 10 per cent fines value test shows a good correlation with the standard crushing value test for strong aggregates while for weaker aggregates this test is more sensitive and gives a truer picture of the differences between more or less weak samples. It should be noted that in the 10 per cent fines value test unlike the crushing value test, a higher numerical result denotes a higher strength of the aggregate. The detail of this test is given at the end of this chapter under testing of aggregate.

Aggregate Impact Value

With respect to concrete aggregates, toughness is usually considered the resistance of the material to failure by impact. Several attempts to develop a method of test for aggregates impact value have been made. The most successful is the one in which a sample of standard aggregate kept in a mould is subjected to fifteen blows of a metal hammer of weight 14 Kgs. falling from a height of 38 cms. The quantity of finer material (passing through 2.36 mm) resulting from pounding will indicate the toughness of the sample of aggregate. The ratio of the weight of the fines (finer than 2.36 mm size) formed, to the weight of the total sample taken is expressed as a percentage. This is known as aggregate impact value IS 283-1970 specifies that aggregate impact value shall not exceed 45 per cent by weight for aggregate used for concrete other than wearing surface and 30 per cent by weight, for concrete for wearing surfaces, such as run ways, roads and pavements.

Aggregate Abrasion Value

Apart from testing aggregate with respect to its crushing value, impact resistance, testing the aggregate with respect to its resistance to wear is an important test for aggregate to be used for road constructions, ware house floors and pavement construction. Three tests are in common use to test aggregate for its abrasion resistance. (*i*) Deval attrition test (*ii*) Dorry abrasion test (*iii*) Los Angels test.

- Deval Attrition Test

In the Deval attrition test, particles of known

weight are subjected to wear in an iron cylinder rotated 10000 times at certain speed. The proportion of material crushed finer than 1.7 mm size is expressed as a percentage of the original material taken. This percentage is taken as the attrition value of the aggregate. This test has been covered by IS 2386 (Part IV) – 1963. But it is pointed out that wherever possible Los Angeles test should be used.

- Dorry Abrasion Test

This test is not covered by Indian Standard Specification. The test involves in subjecting a cylindrical specimen of 25 cm height and 25 cm.

Good rock should show an abrasion value of not less than 17. A rock sample with a value of less than 14 would be considered poor.

- Los Angeles Test

Los Angeles test was developed to overcome some of the defects found in Deval test. Los Angeles test is characterised by the quickness with which a sample of aggregate may be tested. The applicability of the method to all types of commonly used aggregate makes this method popular. The test involves taking specified quantity of standard size material along with specified number of abrasive charge in a standard cylinder and revolving if for certain specified revolutions. The particles smaller than 1.7 mm size is separated out. The loss in weight expressed as percentage of the original weight taken gives the abrasion value of the aggregate. The abrasion value should not be more than 30 per cent for wearing surfaces and not more than 50 per cent for concrete other than wearing surface. Table 3.4 gives average values of crushing strength of rocks, aggregate crushing value, abrasion value, impact value and attrition value for different rock groups.

Modulus of Elasticity

Modulus of elasticity of aggregate depends on its composition, texture and structure. The modulus of elasticity of aggregate will influence the properties of concrete with respect to shrinkage and elastic behaviour and to very small extent creep of concrete. Many studies have been conducted to investigate the influence of modulus of elasticity of aggregate on the properties of concrete. One of the studies indicated that the '*E*' of aggregate has a decided effect on the elastic property of concrete and that the relation of '*E*' of aggregate to that of the concrete is not a linear function, but may be expressed as an equation of exponential type.[3.4]

Table 3.4. Average Test Values For Rocks of Different Groups

Rock Group	*Crushing Strength MPa*	*Aggregate crushing value*	*Abrasion value*	*Impact value*	*Attrition value*		*Specific gravity*
					Dry	*Wet*	
Basalt	207	12	17.6	16	3.3	5.5	2.85
Flint	214	17	19.2	17	3.1	2.5	2.55
Gabbro	204	-	18.7	19	2.5	3.2	2.95
Granite	193	20	18.7	13	2.9	3.2	2.69
Gritstone	229	12	18.1	15	3.0	5.3	2.67
Hornfels	354	11	18.8	17	2.7	3.8	2.88
Limestone	171	24	16.5	9	4.3	7.8	2.69

Porphyry	239	12	19.0	20	2.6	2.6	2.66
Quartizite	339	16	18.9	16	2.5	3.0	2.62
Schist	254	-	18.7	13	3.7	4.3	2.76

Bulk Density

The bulk density or unit weight of an aggregate gives valuable informations regarding the shape and grading of the aggregate. For a given specific gravity the angular aggregates show a lower bulk density. The bulk density of aggregate is measured by filling a container of known volume in a standard manner and weighing it. Bulk density shows how densely the aggregate is packed when filled in a standard manner. The bulk density depends on the particle size distribution and shape of the particles. One of the early methods of mix design make use of this parameter bulk density in proportioning of concrete mix. The higher the bulk density, the lower is the void content to be filled by sand and cement. The sample which gives the minimum voids or the one which gives maximum bulk density is taken as the right sample of aggregate for making economical mix. The method of determining bulk density also gives the method for finding out void content in the sample of aggregate.

For determination of bulk density the aggregates are filled in the container and then they are compacted in a standard manner. The weight of the aggregate gives the bulk density calculated in kg/litre or kg/m^3. Knowing the specific gravity of the aggregate in saturated and surface-dry condition, the void ratio can also be calculated.

$$\text{Percentage voids} = \frac{Gs - \blacksquare}{Gs} \times 100$$

where Gs = specific gravity of the aggregate and $\blacksquare$ = bulk density in kg/litre.

Bulk density of aggregate is of interest when we deal with light weight aggregate and heavy weight aggregate. The parameter of bulk density is also used in concrete mix design for converting the proportions by weight into proportions by volume when weigh batching equipments is not available at the site.

Specific Gravity

In concrete technology, specific gravity of aggregates is made use of in design calculations of concrete mixes. With the specific gravity of each constituent known, its weight can be converted into solid volume and hence a theoretical yield of concrete per unit volume can be calculated. Specific gravity of aggregate is also required in calculating the compacting factor in connection with the workability measurements. Similarly, specific gravity of aggregate is required to be considered when we deal with light weight and heavy weight concrete. Average specific gravity of the rocks vary from 2.6 to 2.8.

Absorption and Moisture Content

Some of the aggregates are porous and absorptive. Porosity and absorption of aggregate will affect the water/cement ratio and hence the workability of concrete. The porosity of aggregate will also affect the durability of concrete when the concrete is subjected to freezing and thawing and also when the concrete is subjected to chemically aggressive liquids.

The water absorption of aggregate is determined by measuring the increase in weight of an oven dry sample when immersed in water for 24 hours. The ratio of the

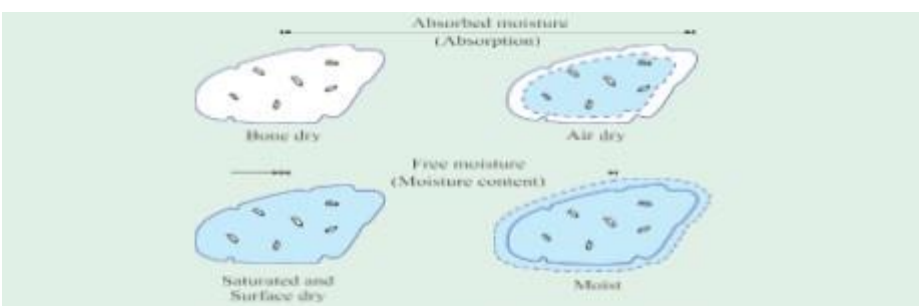


Fig. 3.1. Diagrammatic representation of Moisture in Aggregate.

a significant factor rather than the 24 hours absorption of the aggregate. It may be more realistic to consider that absorption capacity of the aggregates which is going to be still less owing to the sealing of pores by coating of cement particle particularly in rich mixes. In allowing for extra water to be added to a concrete mix to compensate for the loss of water due to absorption, proper appreciation of the absorption in particular time interval must be made rather than estimating on the basis of 24 hours absorption.

In proportioning the materials for concrete, it is always taken for granted that the aggregates are saturated and surface dry. In mix design calculation the relative weight of the aggregates are based on the condition that the aggregates are saturated and surface dry. But in practice, aggregates in such ideal condition is rarely met with. Aggregates are either dry and absorptive to various degrees or they have surface moisture. The aggregates may have been exposed to rain or may have been washed in which case they may contain surface moisture or the aggregates may have been exposed to the sun for a long time in which case they are absorptive. Fine aggregates dredged from river bed usually contains surface moisture. When stacked in heap the top portion of the heap may be comparatively dry, but the lower portion of the heap usually contains certain amount of free moisture. It should be noted that if the aggregates are dry they absorb water from the mixing water and thereby affect the workability and, on the other hand, if the aggregates contain surface moisture they contribute extra water to the mix and there by increase the water/cement ratio. Both these conditions are harmful for the quality of concrete. In making quality concrete, it is very essential that corrective measures should be taken both for absorption and for free moisture so that the water/cement ratio is kept exactly as per the design.

Very often at the site of concrete work we may meet dry coarse aggregate and moist fine aggregate. The absorption capacity of the coarse aggregate is of the order of about 0.5 to 1 per cent by weight of aggregate. A higher absorption value may be met with aggregates derived from sand stone or other soft and porous rocks. Recently it was observed that the rocks excavated in the cuttings of Pune-Mumbai express highway, showed absorption of around 4%. unusualy high for rock of the type Deccan trap. The high absorption characteristic has presented plenty of problems for using such stone aggregate for 40 MPa Pavement Quality

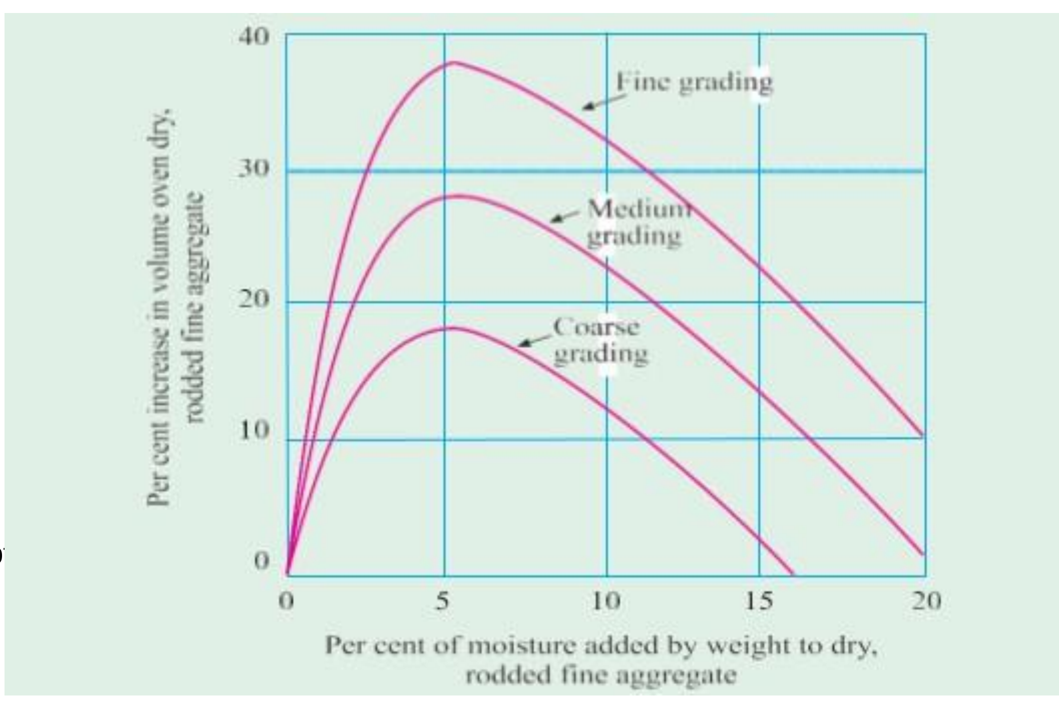
Concrete (PQC). The natural fine aggregates often contain free moisture anything from one to ten per cent or more. Fig. 3.1 shows a diagrammatic representation of moisture in aggregates.

Free moisture in both coarse aggregate and fine aggregate affects the quality of concrete in more than one way. In case of weigh batching, determination of free moisture content of the aggregate is necessary and then correction of water/cement ratio to be effected in this regard. But when volume batching is adopted, the determination of moisture content of fine aggregate does not become necessary but the consequent bulking of sand and correction of volume of sand to give allowance for bulking becomes necessary.

Bulking of Aggregates

The free moisture content in fine aggregate results in bulking of volume. Bulking phenomenon can be explained as follows:

Free moisture forms a film around each particle. This film of moisture exerts what is known as surface tension which keeps the neighbouring particles away from it. Similarly, the force exerted by surface tension keeps every particle away from each other. Therefore, no point contact is possible between the particles. This causes bulking of the volume. The extent of surface tension and consequently how far the adjacent particles are kept away will depend upon the percentage of moisture content and the particle size of the fine aggregate. It is interesting to note that the bulking increases with the increase in moisture



content upto a certain limit and beyond that the further increase in the moisture content results in the decrease in the volume and at a moisture content representing saturation point, the fine aggregate shows no bulking. It can be seen from Fig. 3.2 that fine sand bulks more and coarse sand bulks less. From this it follows that the coarse aggregate also bulks but the bulking is so little that it is always neglected. Extremely fine sand and particularly the manufactured fine aggregate bulks as much as about 40 per cent.

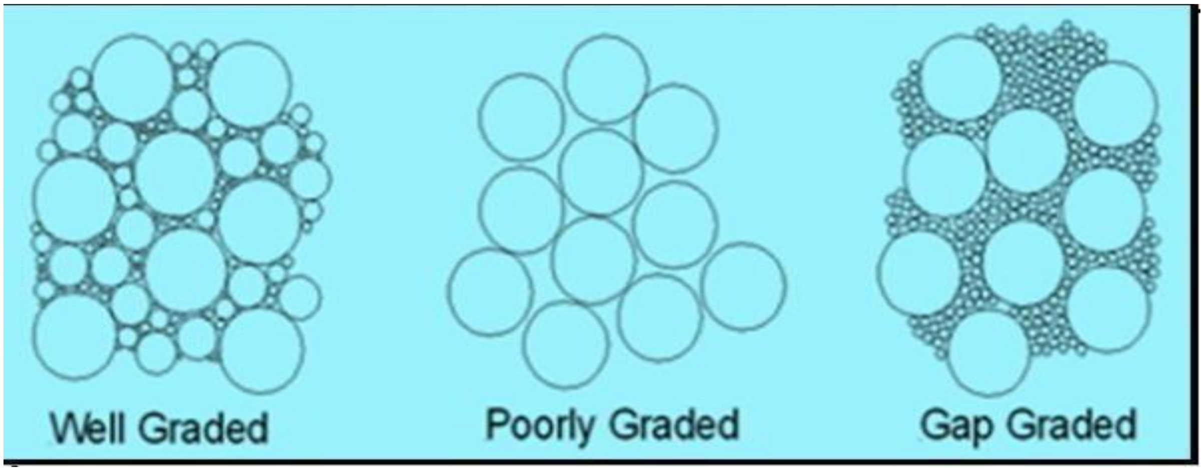
Due to the bulking, fine aggregate shows completely unrealistic volume. Therefore, it is absolutely necessary that consideration must be given to the effect of bulking in proportioning the concrete by volume. If cognisance is not given to the effect of bulking, in case of volume batching, the resulting concrete is likely to be undersanded and harsh. It will also affect the yield of concrete for a given cement content.

The extent of bulking can be estimated by a simple field test. A sample of moist fine aggregate is filled into a measuring cylinder in the normal manner. Note down the level, say h_1. Pour water into the measuring cylinder and completely inundate the sand and shake it. Since the volume of the saturated sand is the same as that of the dry sand, the inundated sand completely offsets the bulking effect. Note down the level of the sand say, h_2. Then $h_1 – h_2$ shows the bulking of the sample of sand under test.

❖ Gap Graded Aggregates:-

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

tes.



Aggregate gradation

It has been seen that the size of voids existing between a particular size of aggregate is of the order of 2 or 3 size lower than that fraction. In other words, the void size existing between 40 mm aggregate is of the size equal to 10 mm or possibly 4.75 mm or the size of voids occurring when 20 mm aggregate is used will be in the order of say 1.18 mm or so. Therefore, along with 20 mm aggregate, only when 1.18 mm aggregate size is used, the sample will contain least voids and concrete requires least matrix. The following advantages are claimed for gap graded concrete:

(i) Sand required will be of the order of about 26 per cent as against about 40 per cent in the case of continuous grading.

(ii) Specific surface area of the gap graded aggregate will be low, because of high percentage of C.A. and low percentage of F.A.

(iii) Requires less cement and lower water/cement ratio.

(iv) Because of point contact between C.A. to C.A. and also on account of lower cement and matrix content, the drying shrinkage is reduced.

It was also observed that gap graded concrete needs close supervision, as it shows greater proneness to segregation and change in the anticipated workability. In spite of many claims of the superior properties of gap graded concrete, this method of grading has not become more popular than conventional continuous grading.

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**.

Advantages of gap grading

1. Requirements of sand is 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.

❖ .Heat of Hydration

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. This is clearly seen if freshly mixed cement is put in a vaccum flask and the temperature of the mass is read at intervals. The study and control of the heat of hydration becomes important in the construction of concrete dams and other mass concrete constructions. It has been observed that the temperature in the interior of large mass concrete is 50°C above the original temperature of the concrete mass at the time of placing and this high temperature is found to persist for a prolonged period. Fig 1.2 shows the pattern of liberation of heat from setting cement and during early hardening period.

On mixing cement with water, a rapid heat evolution, lasting a few minutes, occurs. This heat evolution is probably due to the reaction of solution of aluminates and sulphates (ascending peak A). This initial heat evolution ceases quickly when the solubility of aluminate is depressed by gypsum. (decending peak A). Next heat evolution is on account of formation of ettringite and also may be due to the reaction of C_3S (ascending peak B). Refer Fig. 1.3. Different compounds hydrate at different rates and liberate different quantities of heat. Fig. 1.3 shows the rate of hydration of pure compounds. Since retarders are added to control the flash setting properties of C_3A, actually the early heat of hydration is mainly contributed from the hydration of C_3S. Fineness of cement also influences the rate of development of heat but not the total heat. The total quantity of heat generated in the complete hydration will depend upon the relative quantities of the major compounds present in a cement.

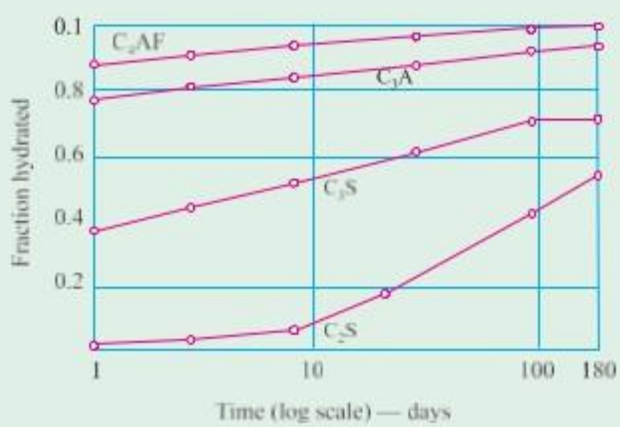


Fig. 1.3. Rate of Hydration of Pure Compounds.

Compound	*Heat of hydration at the given age (cal/g)*		
	3 days	*90 days*	*13 years*
C_3S	58	104	122
C_2S	12	42	59
C_3A	212	311	324

C_4AF	69	98	102

Since the heat of hydration of cement is an additive property, it can be predicted from an expression of the type $H = aA + bB + cC + dD$

Where H represents the heat of hydration, A, B, C, and D are the percentage contents of C_3S, C_2S, C_3A and C_4AF. and a, b, c and d are coefficients representing the contribution of 1 per cent of the corresponding compound to the heat of hydration.

Normal cement generally produces 89-90 cal/g in 7 days and 90 to 100 cal/g in 28 days. The hydration process is not an instantaneous one. The reaction is faster in the early period and continues idenfinitely at a decreasing rate. Complete hydration cannot be obtained under a period of one year or more unless the cement is very finely ground and reground with excess of water to expose fresh surfaces at intervals. Otherwise, the product obtained shows unattacked cores of tricalcium silicate surrounded by a layer of hydrated silicate, which being relatively impervious to water, renders further attack slow. It has been observed that after 28 days of curing, cement grains have been found to have hydrated to a depth of only 4m. It has also been observed that complete hydration under normal condition is possible only for cement particles smaller than 50m.

A grain of cement may contain many crystals of C_3S or others. The largest crystals of C_3S or C_2S are about 40m. An average size would be 15-20m. It is probable that the C_2S crystals present in the surface of a cement grain may get hydrated and a more reactive compound like C_3S lying in the interior of a cement grain may not get hydrated.

The hydrated product of the cement compound in a grain of cement adheres firmly to the unhydrated core in the grains of cement. That is to say unhydrated cement left in a grain of cement will not reduce the strength of cement mortar or concrete, as long as the products of hydration are well compacted. Abrams obtained strength of the order of 280 MPa using mixes with a water/cement ratio as low as 0.08. Essentially he has applied tremendous pressure to obtain proper compaction of such a mixture. Owing to such a low water/cement ratio, hydration must have been possible only at the surface of cement grains, and a considerable portion of cement grains must have remained in an unhydrated condition.

The present day High Performance concrete is made with water cement ratio in the region of 0.25 in which case it is possible that a considerable portion of cement grain remains unhydrated in the core. Only surface hydration takes place. The unhydrated core of cement grain can be deemed to work as very fine aggregates in the whole system.

Calcium Silicate Hydrates

It makes up 50-60 per cent of the volume of solids in a completely hydrated cement paste. The fact that term C-S-H is hyphenated signifies that C-S-H is not a well defined compound.The morphology of C-S-H shows a poorly crystalline fibrous mass.

It was considered doubtful that the product of hydration of both C_3S and C_2S results in the formation of the same hydrated compound. But later on it was seen that ultimately the hydrates of

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

or it can be written as $2C_3S + 6H \rightarrow C_3S_2H_3 + 3Ca(OH)_2$ The corresponding weights involved are

$$100 \quad + \quad 24 \rightarrow 75 \quad + \quad 49.$$ Similarly,

$$2\,(2\,CaO.SiO_2) + 4\,H_2O \rightarrow 3Cao.2\,SiO_2.\,3H_2O + Ca(OH)_2$$

or it can be written as

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

The corresponding weights involved are

$$100 \quad + \quad 21 \rightarrow 99 \quad + \quad 22$$

C_3S and C_2S will turn out to be the same. The following are the approximate equations showing the reactions of C_3S and C_2S with water.

However, the simple equations given above do not bring out the complexities of the actual reactions.

It can be seen that C_3S produces a comparatively lesser quantity of calcium silicate hydrates and more quantity of $Ca(OH)_2$ than that formed in the hydration of C_2S. $Ca(OH)_2$ is not a desirable product in the concrete mass, it is soluble in water and gets leached out making the concrete porous, particularly in hydraulic structures. Under such conditions it is useful to use cement with higher percentage of C_2S content.

C_3S readily reacts with water and produces more heat of hydration. It is responsible for early strength of concrete. A cement with more C_3S content is better for cold weather concreting. The quality and density of calcium silicate hydrate formed out of C_3S is slightly inferior to that formed by C_2S. The early strength of concrete is due to C_3S.

C_2S hydrates rather slowly. It is responsible for the later strength of concrete. It produces less heat of hydration. The calcium silicate hydrate formed is rather dense and its specific surface is higher. In general, the quality of the proudct of hydration of C_2S is better than that produced in the hydration of C_3S. Fig 1.4 shows the development of strength of pure compounds.

Calcium Hydroxide

The other products of hydration of C_3S and C_2S is calcium hydroxide. In contrast to the C-S-H, the calcium hydroxide is a compound with a distinctive hexagonal prism morphology. It constitutes 20 to 25 per cent of the volume of solids in the hydrated paste. The lack of durability of concrete, is on account of the presence of calcium hydroxide. The calcium hydroxide also reacts with sulphates present in soils or water to form calcium sulphate which further reacts with C_3A and cause deterioration of concrete. This is known as sulphate attack. To reduce the quantity of $Ca(OH)_2$ in concrete and to overcome its bad effects by converting it into cementitious product is an advancement in concrete technology.

Calcium Aluminate Hydrates

The hydration of aluminates has been the subject of numerous investigations, but there is still some uncertainty about some of the reported products. Due to the hydration of C_3A ,a calcium aluminate system $CaO – Al_2O_3 – H_2O$ is formed. The cubic compound C_3AH_6 is probably the only stable compound formed which remains stable upto about 225°C.

The reaction of pure C_3A with water is very fast and this may lead to flash set. To prevent this flash set, gypsum is added at the time of grinding the cement clinker. The quantity of gypsum added has a bearing on the quantity of C_3A present. The hydrated aluminates do not contribute anything to the strength of concrete. On the other hand, their presence is harmful to the durability of concrete particularly where the concrete is likely to be attacked by sulphates. As it hydrates very fast it may contributea little to the early strength.

On hydration, C_4AF is believed

to form a system of the form $CaO – Fe_2O_3 – H_2O$. A hydrated calcium ferrite of the form C_3FH_6 is comparatively more stable. This hydrated product also does not contribute anything to the strength. The hydrates of C_4AF show a comparatively higher resistance to the attack of sulphates than the hydrates of calcium aluminate.

From the standpoint of hydration, it is convenient to discuss C_3A and C_4AF together, because the products formed in the presence of gypsum are similar. Gypsum and alkalies go into solution quickly and the solubility of C_3A is depressed. Depending upon the concentration of aluminate and sulphate ions in solution, the pricipitating crystalline product is either the calcium aluminate trisulphate hydrate ($C_6A\ S\ _3H_{32}$) or calcium aluminate monosulhphate hydrate ($C_4A\ S\ H_{18}$). The calcium aluminate trisulphate hydrate is known as ettringite.

Ettringite is usually the first to hydrate and crystallise as short prismatic needle on account of the high sulphate/aluminate ratio in solution phase during the first hour of hydration. When sulphate in solution gets depleted, the aluminate concentration goes up due to renewed hydration of C_3A and C_4AF. At this stage ettringite becomes unstable and is gradually converted into mono-sulphate, which is the final product of hydration of portland cements containing more than 5 percent C_3A.

The amount of gypsum added has significant bearing on the quantity of aluminate in the cement. The maintenance of aluminate-to-sulphate ratio balance the normal setting

behaviour of cement paste. The various setting phenomena affected by an imbalance in the A/S ratio is of practical significance in concrete technology.

Many theories have been put forward to explain what actually is formed in the hydration of cement compounds with water. It has been said earliiar that product consisting of ($CaO.SiO_2.H_2O$) and $Ca(OH)_2$ are formed in the hydration of calcium silicates. $Ca(OH)_2$ is an unimportant product, and the really significant product is ($CaO.SiO_2.H_2O$). For simplicity's sake this product of hydration is sometime called tobermorite gel because of its structural similarity to a naturally occurring mineral tobermorite. But very commonly the product of hydration is referred to as C – S – H gel.

It may not be exactly correct to call the product of hydrations as gel. Le chatelier identified the products as crystalline in nature and put forward his crystalline theory. He explained that the precipitates resemble crystals interlocked with each other. Later on Michaelis put forward his colloidal theory wherein he considered the precipitates as colloidal mass, gelatinous in nature. It is agreed that an element of truth exists in both these theories. It is accepted now that the product of hydration is more like gel, consisting of poorly formed, thin, fibrous crystals that are infinitely small. A variety of transitional forms are also believed to exist and the whole is seen as bundle of fibres, a fluffy mass with a refractive index of 1.5 to 1.55, increasing with age.

Since the gel consists of crystals, it is porous in nature. It is estimated that the porosity of gel is to the extent of 28%. The gel pores are filled with water. The pores are so small that the specific surface of cement gel is of the order of 2 million sq. cm. per gm. of cement. The porosity of gel can be found out by the capillary condensation method or by the mercury porosimetry method.

❖ Structure of Hydrated Cement

To understand the behaviour of concrete, it is necessary to acquaint ourselves with the structure of hydrated hardened cement paste. If the concrete is considered as two phase material, namely, the paste phase and the aggregate phase, the understanding of the paste phase becomes more important as it influences the behaviour of concrete to a much greater extent. It will be discussed later that the strength, the permeability, the durability, the drying shrinkage, the elastic properties, the creep and volume change properties of concrete is greatly influenced by the paste structure. The aggregate phase though important, has lesser influence on the properties of concrete than the paste phase. Therefore, in our study to understand concrete, it is important that we have a deep understanding of the structure of the hydrated hardened cement paste at a phenomenological level.

❖ Testing of Aggregates

1) Test for Determination of Flakiness Index

The flakiness index of aggregate is the percentage by weight of particles in it whose least dimension (thickness) is less than three-fifths of their mean dimension. The test is not applicable to sizes smaller than 6.3 mm. This test is conducted by using a metal thickness gauge, of the description shown in Fig.

3.9. A sufficient quantity of aggregate is taken such that a minimum number of 200 pieces of any fraction can be tested. Each fraction is gauged in turn for thickness on the metal gauge. The total amount passing in the guage is weighed to an accuracy of 0.1 per cent of the weight of the samples taken. The flakiness index is taken as the total weight of the material passing the various thickness gauges expressed as a percentage of the total weight of the sample taken. Table 3.18 shows the standard dimensions of thickness and length gauges.

Size of Aggregate Thickness		*Length of Gauge* mm*	*Gauge† mm*
Passing through IS Sieve	*Retained on IS Sieve*		
63 mm	50 mm	33.90	–
50 mm	40 mm	27.00	81.0
40 mm	25 mm	19.50	58.5
31.5 mm	25 mm	16.95	–
25 mm	20 mm	13.50	40.5
20 mm	16 mm	10.80	32.4
16 mm	12.5 mm	8.55	25.6
12.5 mm	10.0 mm	6.75	20.2
10.0 mm	6.3 mm	4.89	14.7

Shows Dimensions of Thickness and Length Gauges (IS: 2386 (Part I) – 1963)

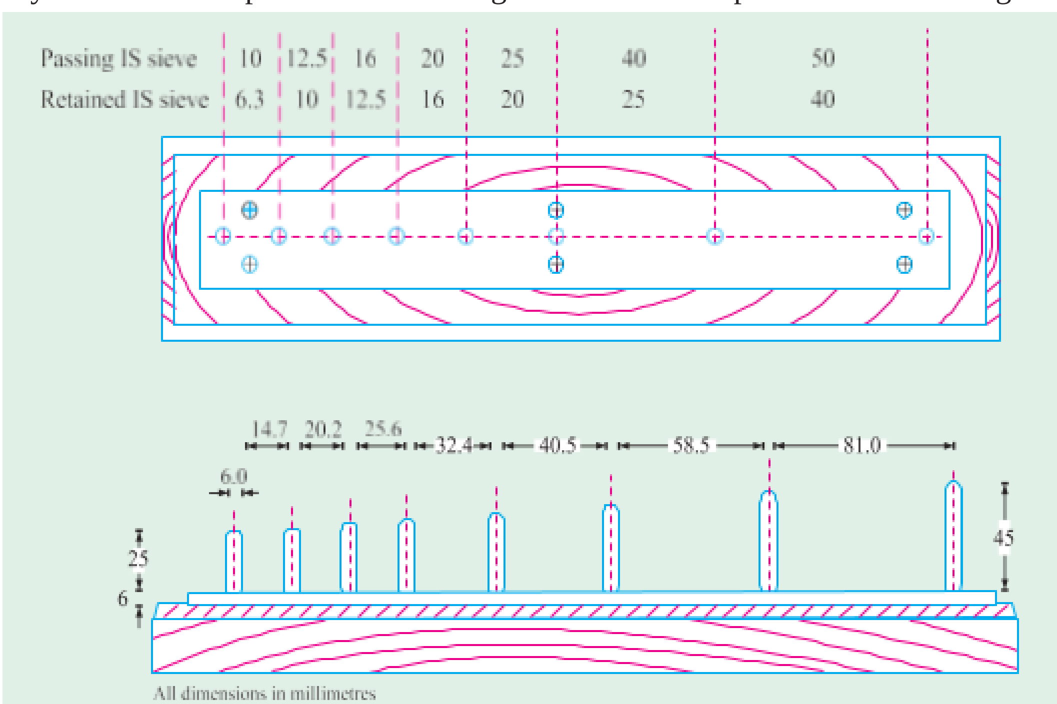
* This dimension is equal to 0.6 times the mean Sieve size.

† This dimension is equal to 1.8 times the mean Sieve size.

2) Test for Determination of Elongation Index

The elongation index on an aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than 1.8 times their mean dimension. The elongation index is not applicable to sizes smaller than 6.3 mm.

This test is conducted by using metal length guage of the description shown in Fig. 3.10. A sufficient quantity of aggregate is taken to provide a minimum number of 200 pieces of any fraction to be tested. Each fraction shall be gauged individually for length on the metal guage. The guage length used shall be that specified in column of 4 of Table 3.18 for the appropriate size of material. The total amount retained by the guage length shall be weighed to an accuracy of at least 0.1 per cent of the weight of the test samples taken. The elongation index is



the total weight of the material retained on the various length gauges expressed as a percentage of the total weight of the sample gauged. The presence of elongated particles in excess of 10 to 15 per cent is generally considered undesirable, but no recoganised limits are laid down.

3) Test for Determination of clay, fine silt and fine dust

This is a gravimetric method for determining the clay, fine silt and fine dust which includes particles upto 20 microns.

The sample for test is prepared from the main sample, taking particular care that the test sample contains a correct proportion of the finer material. The amount of sample taken for the test is in accordance with

Weight of Sample for Determination of Clay, Fine Silt and Fine Dust

Maximum size present in substantial proportions mm	*Approximate weight of sample for Test Kg*
63 to 25	6
20 to 12.5	1
10 to 6.3	0.5
4.75 or smaller	0.3

Sedimentation pipette of the description shown in Fig. 3.11 is used for determination of clay and silt content. In the case of fine aggregate, approximately 300 gm. of samples in the air-dry condition, passing the 4.75 mm IS Sieve, is weighed and placed in the screw topped glass jar, together with 300 ml of diluted sodium oxalate solution. The rubber washer and cap are fixed. Care is taken to ensure water tightness. The jar is then rotated about its long axis, with this axis horizontal, at a speed of 80 ± 20 revolutions per minute for a period of 15 minutes. At the end of 15 minutes the suspension is poured into 1000 ml measuring cylinder and the residue washed by gentle swirling and decantation of successive 150 ml portions of sodium oxalate solution, the washings being added to the cylinder until the volume is made upto 1000 ml.

In the case of coarse aggregate the weighed sample is placed in a suitable container, covered with a measured volume of sodium oxalate solution (0.8 gm per litre), agitated vigorously to remove all fine material adhered and the liquid suspension transferred to the 1000 ml measuring cylinder. This process is repeated till all clay material has been transferred to the cylinder. The volume is made upto 1000 ml with sodium oxalate solution.

The suspension in the measuring cylinder is thoroughly mixed. The pipette A is then gently lowered until the pipette touches the surface of the liquid, and then lowered a further 10 cm into the liquid. Three minutes after placing the tube in position, the pipette A and the bore of tap B is filled by opening B and applying gentle suction at C. A small surplus may be drawn up into the bulb between tap B and tube C, but this is allowed to run away and any solid matter is washed out with distilled water from E. The pipette is then removed from the measuring cylinder and its contents run into a weighed container. The contents of the container is dried at 100°C to 110°C to constant weight, cooled and weighed.

The percentage of the fine slit and clay or fine dust is calculated from the formula.

$$\frac{100}{W_1}\left(\frac{1000\,W_2}{V} - 0.8\right)$$

where W_1 = weight in gm of the original sample.

W_2= weight in gm of the dried residue

V= volume in ml of the pipette

4) Test for Determination of Organic Impurities

This test is an approximate method for estimating whether organic compounds are present in the natural sand in an objectionable quantity or within the permissible limit. The sand from the natural source is tested as delivered and without drying. A 350 ml graduated clear glass bottle is filled to the 75 ml mark with 3 per cent solution of sodium hydroxide in water. The sand is added gradually until the volume measured by the sand layer is 125 ml. The volume is then made up to 200 ml by adding more solution. The bottle is then stoppered and shaken vigorously. Roding also may be permitted to dislodge any organic matter adhering to the natural sand by using glass rod. The liquid is then allowed to stand for 24 hours. The colour of this liquid after 24 hours is compared with a standard solution freshly prepared, as follows:

Add 2.5 ml of 2 per cent solution of tannic acid in 10 per cent alcohol, to 97.5 ml of a 3 per cent sodium hydroxide solution. Place in a 350 ml. bottle, stopper, shake vigorously and allow to stand for 24 hours before comparison with the solution above and described in the preceding paragraph. Alternatively, an instrument or coloured acetate sheets for making the comparison can be obtained, but it is desirable that these should be verified on receipt by comparison with the standard solution.

5) Test for Determination of Specific Gravity

Indian Standard Specification IS : 2386 (Part III) of 1963 gives various procedures to find out the specific gravity of different sizes of aggregates. The following procedure is applicable to aggregate size larger than 10 mm.

A sample of aggregate not less than 2 kg is taken. It is thoroughly washed to remove the finer particles and dust adhering to the aggregate. It is then placed in a wire basket and immersed in distilled water at a temperature between 22° to 32°C. Immediately after immersion, the entrapped air is removed from the sample by lifting the basket containing it 25 mm above the base of the tank and allowing it to drop 25 times at the rate of about one drop per sec. During the operation, care is taken that the basket and aggregate remain completely immersed in water. They are kept in water for a period of 24 ± 1/2 hours afterwards. The basket and aggregate are then jolted and weighed (weight A_1) in water at a temperature 22° to 32° C. The basket and the aggregate are then removed from water and allowed to drain for a few minutes and then the aggregate is taken out from the basket and placed on dry cloth and the surface is gently dried with the cloth. The aggregate is transferred to the second dry cloth and further dried. The empty basket is again immersed in water, jolted 25 times and weighed in water (weight A_2). The aggregate is exposed to atmosphere away from direct sunlight for not less than 10 minutes until it appears completely surface dry. Then the aggregate is weighed in air (weight B). Then the aggregate is kept in the oven at a temperature of 100 to 110°C and maintained at this temperature for 24 ± 1/2 hours. It is then cooled in the air-tight container, and weighed (weight C).

Specific Gravity = $\frac{C}{\text{[illegible]}}$; Apparent Sp. Gravity = $\frac{C}{\text{[illegible]}}$

Water absorption = $\frac{100\,(B - C)}{C}$

Where, A = the weight in gm of the saturated aggregate in water ($A_1 - A_2$),

B = the weight in gm of the saturated surface-dry aggregate in air, and

C = the weight in gm of oven-dried aggregate in air.

6) Test for Determination of Bulk Density and Voids

Bulk density is the weight of material in a given volume. It is normally expressed in kg per litre. A cylindrical measure preferably machined to accurate internal dimensions is used for measuring bulk density. The size of the container for measuring bulk density is shown in

Size of Container for Bulk Density Test

Size of Largest Particles	*Nominal Capacity*	*Inside Diameter*	*Inside Height*	*Thickness of Metal*
	litre	cm	cm	mm
4.75 mm and under	3	15	17	3.15
Over 4.75 mm to 40 mm	15	25	30	4.00

Over 40 mm	30	35	31	5.00

The cylindrical measure is filled about 1/3 each time with thoroughly mixed aggregate and tamped with 25 strokes by a bullet ended tamping rod, 16 mm diameter and 60 cm long. The measure is carefully struck off level using tamping rod as a straight edge. The net weight of the aggregate in the measure is determined and the bulk density is calculated in kg/litre

Unit -II

Syllabus:

CONCRETE: Workability – Factors affecting workability –Measurement of workability by different tests – Setting times of concrete – Effect of timeand temperature on workability – Segregation & bleeding – Mixing and vibration ofconcrete – Steps in manufacture of concrete – Quality of mixing water.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 compressive & tensile strength - Curing. Compression tests – Tension tests – Factors affecting strength – Flexure tests – Splitting tests

NOTES

❖ Workability

Workability of Concrete is a broad and subjective term describing how easily freshly mixed concrete can be mixed, placed, consolidated, and finished with minimal loss of homogeneity. Workability is a property that directly impacts strength, quality, appearance, and even the cost of labor for placement and finishing operations.

Factors Affecting Workability

- **Water Content of the Mix** -- This is the single most important fact or governing workability of concrete. A group of particles requires a certain amount of water. Water is absorbed on the particle surface, in the volumes between particles, and provides "lubrication" to help the particles move past one another more easily. Therefore, finer particles, necessary for plastic behaviour, require more water. Some side-effects of increased water are loss of strength and possible segregation.
- **Influence of Aggregate Mix Proportions** -- Increasing the proportion of aggregates relative to the cement will decrease the workability of the concrete. Also, any additional fines will require more cement in the mix. An "over sanded" mix will be permeable and less economical. A concrete deficient of fines will be difficult to finish and prone to segregation.

- **Aggregate Properties** -- The ratio of coarse/fine aggregate is not the only factor affecting workability. The gradation and particle size of sands are important. Shape and texture of aggregate will also affect workability. Spherical shaped particles will not have the interaction problems associated with more angular particles. Also, spherical shapes have a low surface/volume ratio, therefore, less cement will be required to coat each particle and more will be available to contribute to the workability of the concrete. Aggregate which is porous will absorb more water leaving less to provide workability. It is important to distinguish between total water content, which includes absorbed water, and free water which is available for improving workability.
- **Time and Temperature** -- In general, increasing temperature will cause an increase in the rate of hydration and evaporation. Both of these effects lead to a loss of workability.
- **Loss of Workability** -- Workability will decrease with time due to several factors; continued slow hydration of C3S and C3A during dormant period, loss of water through evaporation and absorption, increased particle interaction due to the formation of hydration products on the particle surface. Loss of workability is measured as "slump loss" with time.
- **Cement Characteristics** -- Cement characteristics are less important than aggregate properties in determining workability. However, the increased fineness of rapid-hardening cements will result in rapid hydration and increased water requirements, both of which reduce workability.
- **Admixtures** -- In general, air-entraining, water-reducing, and set-retarding admixtures will all improve workability. However, some chemical admixtures will react differently with cements and aggregates and may result in reduced workability.

❖ **Measurement of Workability**

Workability, a term applied to many concrete properties, can be adequately measured by three characteristics:

1. Compatibility, the ease with which the concrete can be compacted and air void

removed.

2. Mobility, ease with which concrete can flow into forms and around reinforcement.
3. Stability, ability for concrete to remain stable and homogeneous during handling and vibration without excessive segregation.

Different empirical measurements of workability have been developed over the years. None of these tests measure workability in terms of the fundamental properties of concrete. However, the following tests have been developed:

- **Subjective Assessment --** The oldest way of measuring workability based on the judgement and experience of the engineer. Unfortunately, different people see things, in this case concrete, differently.
- **Slump Test --** The oldest, most widely used test for determining workability. The device is a hollow cone-shaped mould. The mould is filled in three layers of each volume. Each layer is rodded with a 16mm steel rod 25 times. The mould is then lifted away and the change in the height of the concrete is measured against the mould. The slump test is a measure of the resistance of concrete to flow under its own weight.

slump is a general reduction in height of the mass without any breaking up. Shear slump indicates a lack of cohesion, tends to occur in harsh mixes. This type of result implies the concrete is not suitable for placement. Collapse slump generally indicates a very wet mix. With different aggregates or mix properties, the same slump can be measured for very different concretes.

- **Compaction Test** -- Concrete strength is proportional to its relative density. A test to determine the compaction factor was developed in 1947. It involves dropping a volume of concrete from one hopper to another and measuring the volume of concrete in the final hopper to that of a fully compacted volume. This test is difficult to run in the field and is not practical for large aggregates (over 1 in.).
- **Flow Test** -- Measures a concretes ability to flow under vibration and provides information on its tendency to segregate. There are a number of tests available but none are recognized by ASTM. However, the flow table test described for mortar flows is occasionally used.
- **Remoulding Test** -- Developed to measure the work required to cause concrete not only to flow but also to conform to a new shape.

    - **Vebe Test** - A standard slump cone is cast, the mould removed, and a transparent disk placed on top of the cone. The sample is then vibrated till the disk is completely covered with mortar. The time required for this is called the Vebe time.

    - **Thaulow Drop Table** - Similar to the Vebe test except a cylinder of concrete is remoulded on a drop table. The number of drops to achieve this remoulding is counted.

    - **Penetration Test** -- A measure of the penetration of some indenter into concrete. Only the Kelly ball penetration test is included in the ASTM Standards. The Kelly ball penetration test measures the penetration of a 30 lb. hemisphere into fresh concrete. This test can be performed on concrete in a buggy, open truck, or in form if they are not too narrow. It can be compared to the slump test for a measure of concrete consistency.

Test to Measure the workability of concrete:-

Slump Test

Compacting Factor Test

Flow Test

Vee-Bee Consistometer Test

Kelly Ball Test

1) Slump Cone Test:-

The concrete slump test or slump cone test is the most common test for workability of freshly mixed concrete which can be performed either at the working site/field or in the laboratory. To maintain the workability and quality of fresh concrete, it is necessary to check batch by batch inspection of the concrete slump. This can be easily done with the concrete slump test. The slump test is the simplest test to determine workability of concrete that involves low cost and provides immediate results.

Apparatus required

Slump cone mould, scale, tamppping rod

Procedure

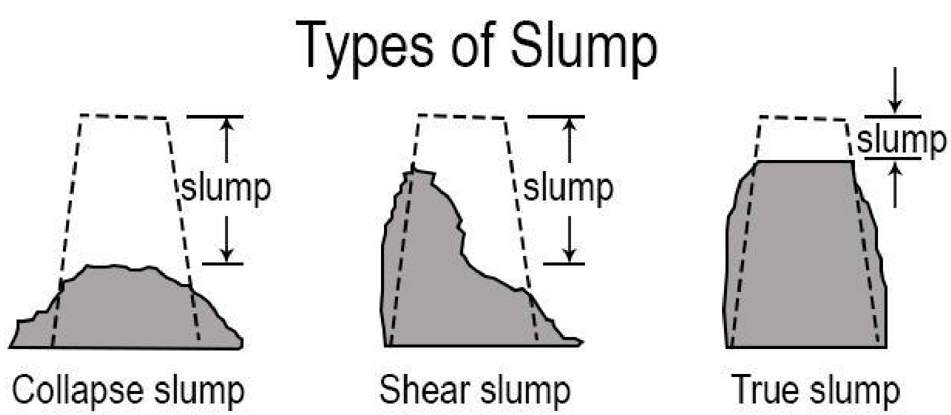
The mould shall be placed on a smooth, horizontal, rigid and non-absorbent surface. The mould should be firmly held in place while it is being filled.

The mould shall be filled in four layers; each layer shall be approximately one-quarter of the height of the mould. Each layer shall be tamped with 25 strokes of the rounded end of the tamping rod. The strokes shall be distributed in a uniform manner over the cross-section of the mould.

The bottom layer shall be tamped throughout its depth. After the top layer has been rodded, the concrete shall be struck off level with a trowel or the tamping rod, so that the mould is exactly filled.

If mortar may have leaked out between the mould and the base plate, it shall be cleaned away. Then, the mould shall be removed from the concrete immediately by raising it carefully and slowly in a vertical direction. This allows the concrete to drop and the slump shall be measured immediately by tamping rod shall be placed over the cone to determine the difference between the height of the mould and that of the highest point of the specimen being tested. The decrease in height of slump is measured with a scale. The above test shall be carried out at a place free from vibration or shock, and within a period of two minutes after sampling.

The concrete slump measured shall be recorded in terms of milli-metres. Any concrete slump specimen, which collapses laterally and gives incorrect result; and if this happens, the slump test shall be repeated with another sample. If, in the repeat test, the specimen should shear, the slump shall be measured and the measurement of that sheared specimen shall be recorded.



Full Collapse slump or full failure of slump:

In Full collapse, the concrete collapse completely. It indicates the higher amount of water is mixed to make the concrete.

2) Compaction Factor Test

Compaction factor test works on the principle of determining the degree of compaction achieved by a standard amount of work done by allowing the concrete to fall through a standard height. This is specially designed for laboratory use, but if the circumstances favours, it can also be used on the working site/field.

Compaction factor test of concrete is more precise and sensitive than the concrete slump test; hence it is more favorable and useful for low workable concrete or dry concrete which is generally used when concrete is to be compacted by vibration

- If the compacting factor is 0.78 than it is considered as very low workability of concrete.
- If the compacting factor is 0.85 than it is considered as low workability of concrete,
- If the compacting factor is 0.92 than it is considered as medium workability of concrete,
- If the compacting factor is 0.95 than it is considered as high workability of concrete.

Apparatus

Following apparatus are used for performing the compaction factor test,

- Compacting factor apparatus – It consist of two conical hoppers and one cylindrical mould
- Tamping rod
- Weighing machine

Concrete which is to be tested is placed gently in the upper hopper to its edge, using the hand scoop and level the concrete surface.

02. Open the bottom trapdoor of the upper hopper so that concrete will fall into the lower hopper.

03. Before starting this process, the cylinder should be covered; hence concrete can't enter in the cylinder.

04. Concrete has a tendency to stick, so if concrete sticks in one or both hoppers than concrete can gently be pushed by the steel rod from the top.

05. Immediately after the concrete comes to rest in the lower hopper, the cylinder should be uncovered.

06. Now, open the trap-door of the lower hopper so that concrete can fall into the cylinder.

07. If the excess concrete remains above the top level of the cylinder then, cut off this concrete by using of trowels and level it. After that, wipe and clean the outside surface of the cylinder.

08. Take the weight of the cylinder with concrete **(W1)**. This weight is called as the **weight of partially compacted concrete (W1).**

09. Now, empty the cylinder and refill it with the same concrete. This time concrete is placed in approximately 5 cm thick layers and rammed. Each layer is rammed heavily to obtain full compaction.

10. Level the top surface of the fully compacted concrete at the top of the cylinder.

11. Again, Wipe and clean the outside of the cylinder.

12. Take the weight of the cylinder with concrete **(W2).** This weight is called the **weight of fully compacted concrete(W2)**

13. Now, take the **weight of the empty cylinder(W)**, before taking weight cylinder has to be properly cleaned.

$$\text{Compacting Factor} = \frac{\text{Weight of partially compacted concrete}}{\text{Weight of Fully compacted concrete}} = \frac{W1-W}{W2-W}$$

3) Vee Bee Consistometer

Vee bee consistometer test is a good laboratory test on fresh concrete to measure the workability in an indirect way by using a Vee-Bee consistometer. Vee bee test is usually performed on dry concrete and it is not suitable for very wet concrete. Vee bee consistometer test determines the mobility and to some extent compatibility of concrete. In the vee bee consistometer test vibrator is used instead of jolting. Vee bee test determines the time required for the transformation of concrete by the vibration.

- If vee bee time is up to 20 to 15-10 seconds than concrete is considered as in a very dry consistency.
- If vee bee time is up to 10 to 7-5 seconds than concrete is considered as in a dry consistency.
- If vee bee time is up to 5 to 4-3 seconds than concrete is considered as in a plastic consistency.
- If vee bee time is up to 3 to 2-1 seconds than concrete is considered as in a semi-fluid consistency.

Apparatus:-

Vee bee consistometer is used to perform the vee bee test of concrete, which consists of the following components,

- Vibrating table
- A Metal pot
- A steel metal cone or Slump Cone
- A standard iron rod

Procedure:-

- Place a sheet metal cone/slump cone in the metal pot/cylindrical container of the consistometer.
- Fill the concrete in the slump cone in four layers; each layer should be one-quarter of the height of the slump cone. Tamp each layer with the rounded end of tamping rod for 25 strokes. After the last layer has been tamped than level the surface with a trowel.
- After the levelling of slump cone surface, move and place the transparent glass disc which is attached to swivel arm on the top surface of the slump cone in the metal pot and then note down the reading from the graduated scale as an initial reading.

- Now, remove the slump cone slowly and carefully in the upward direction and wait till the concrete settles in new position. Then lower the transparent glass disc on the top of the concrete and note down the reading from the graduated scale as a final reading.
- Determine the slump value by taking the difference between the final reading and initial reading, which are taken from the graduated rod.
- Now, switch on the vibrator and start the stopwatch allow concrete to spread out in the metal pot.
- The vibrator should be continued till the concrete surface completely adheres uniformly to the transparent glass disc.

And note the time taken for this remoulding process. This time is recorded in seconds.

- **Slump Value = Final Reading – Initial Reading:** Slump value is the difference between the final reading and initial reading, which are taken from the graduated rod.
- **Vee Bee Degree**: In the vee bee consistometer test, the shape of concrete is changed from the slump cone shape to the cylindrical shape in seconds, the required time to change the shape of concrete is known as vee bee degree.

4) Flow Test

The flow test is a laboratory test, which gives an indication of the quality of concrete with respect to consistency or workability and cohesiveness. In the flow test, a standard mass of concrete is subjected to jolting. This test is generally used for high/ very high workability concrete.

Similar laboratory test named ‘Flow Table Test ‘was developed in Germany in1933 and it has been described in ‘BS 1881:105: 1984’. This method is used for the high and very high workable concrete which would exhibit the collapse slump.

Apparatus:-

Following apparatus are used for performing the flow table test,

- Flow table
- Mould
- Scale

Procedure:-

- Clean all the gritty material or dust from the flow table and from inside the mould.
- Place the cone in the marked or middle portion of the flow table.
- Now pour the freshly mixed concrete in the mould in two layers, each layer should be tamped 25 times with tamping rod. If concrete overflows after tamping then level it with the help of a trowel, and excess concrete should be removed off from the table.
- Then, lift the mould vertically upward and let the concrete stand on its own without support.
- Thereafter the table is raised and dropped from 12.5 mm height, 15 times in about 15 seconds.
- Next, measure the diameter of the spread of concrete in about 6 directions and note down the average.

Result for flow table

The flow of concrete: The percentage increase in the average diameter of the spreading concrete over the base diameter of the mould is called the flow of concrete.

$$\text{Flow \%} = \frac{(\text{Spread diameter in cm-25})}{25} \times 100$$

According to **'A.M. Neville, honorary member of the American Concrete Institute'**, this flow table test is appropriate for concrete mixes having a flow of 340 to 600 mm.

Summing up, High workability of concrete is needed where limited vibration or compaction is possible, in hot weather concreting, in the construction of highly congested reinforced elements etc. This flow test of concrete is very helpful for measuring high or very high workability at such locations.

❖ Setting of Concrete

Setting is defined as the onset of rigidity in fresh concrete. Hardening is the development of useable and measurable strength; setting precedes hardening. Both are gradual changes controlled by hydration. Fresh concrete will lose measurable slump before initial set and measurable strength will be achieved after final set.

Setting is controlled by the hydration of C3S. The period of good workability is during the dormant period, (stage 2). Initial set corresponds to the beginning of stage 3, a period of rapid hydration. Final set is the midpoint of this acceleration phase. A rapid increase in temperature is associated with stage 3 hydration, with a maximum rate at final set.

If large amounts of ettringite rapidly form from C3A hydration, the setting times will be reduced. Cements with high percentages of C3A, such as expansive or set-regulated cements, are entirely controlled by ettringite formation.

❖ Segregation and Bleeding

Segregation refers to a separation of the components of fresh concrete, resulting in a non-uniform mix. This can be seen as a separation of coarse aggregate from the mortar, caused from either the settling of heavy aggregate to the bottom or the separation of the aggregate from the mix due to improper placement.

Some factors that increase segregation are:

- Larger maximum particle size (25mm) and proportion of the larger particles
- High specific gravity of coarse aggregate.
- Decrease in the amount of fine particles.
- Particle shape and texture.
- Water/cement ratio.

Good handling and placement techniques are most important in prevention of segregation.

Introduction to concrete segregation:

Segregation occurs when different components of concrete are separated from each other.

The separation is usually due to excessive vibration of the cement, different materials forming concrete mixtures having different weights.

Coarse aggregates settle to the bottom, followed by sand, fines, cement and finally water. This can happen either due to excessive vibration and/or errors in mix design, especially excess water (or excess of plasticizer).

It is a very degrading effect in concrete since the whole mix loses its complete properties because the different constituents don't work together.

Segregation of concrete causes:

1. Inappropriate mixing of concrete with greater water content.
2. Poorly proportional mixing where sufficient matrix is not available for binding aggregates.
3. Dropping concrete from a height as in concrete for columns.
4. Badly designed mixer or worm-out blades.
5. Excessive vibration of concrete.
6. Without any time lag, the immediate, coarse aggregates acting on the concrete are likely to be clamped down, resulting in the movement of the excess of the matrix.

How to prevent segregation of concrete:-

- Ensure that the concrete is mixed properly; the concrete must be mixed at the correct speed in the transit concrete mixer for at least two minutes immediately before discharging.
- Concrete should be laid as soon as possible.
- While transporting the mixture, load carefully.
- Always add new concrete to the concrete face already.
- Limiting the height from where the concrete has fallen.

- Proper precautions in transporting concrete.
- To avoid segregation of concrete, ignore vibration.
- The use of an air-entraining agent reduces isolation appreciably.
- Concrete mixes have to be designed accurately with the optimum amount of water i.e. neither too wet nor too dry.
- Regularly check the efficiency of the mixer regarding sufficient uniformity of distribution of components in every batch.
- The formwork must be watertight so that the paste leaks from the foams; do not vibrate the formwork.
- Do not let the solid flow.
- Use the vibrator precisely.
- Vibrate the concrete only for the proper time; not too long, not too short.
- Use an air-entraining agent such as chemical penetration into the mixture because entered air reduces the risk of isolation.
- If separation is observed in the concrete, the mixture must be accomplished to make it homogeneous again.

Bleeding is defined as the appearance of water on the surface of concrete after it has consolidated but before it is set. Since mixing water is the lightest component of the concrete, this is a special form of segregation. Bleeding is generally the result of aggregates settling into the mix and releasing their mixing water. Some bleeding is normal for good concrete.

However, if bleeding becomes too localized, channels will form resulting in "craters". The upper layers will become too rich in cement with a high w/c ratio causing a weak, porous structure. Salt may crystalize on the surface which will affect bonding with additional lifts of concrete. This formation should always be removed by brushing and washing the surface. Also, water pockets may form under large aggregates and reinforcing bars reducing the bond.

Bleeding may be reduced by:

1. Increasing cement fineness.

2. Increasing the rate of hydration.
3. Using air-entraining admixtures.
4. Reducing the water content.

Causes of bleeding:-

Segregation is the cause of bleeding in the concrete mix. Segregation is the phenomena in which heavy aggregate particles settles down, due to settling of heavy particles, water rises up to the surface and forms a layer. This upward movement of water also carries fine particles of cement with it. The top surface of slabs and pavements will not have good wearing quality.

Bleeding will be more frequent on the surface of concrete, when water to cement ratio is higher. The type of cement used, quantity of fine aggregate also plays a key role in rate of bleeding.

Effects of bleeding:-

- o Due to bleeding concrete loses its homogeneity.

- Bleeding is responsible for causing permeability in concrete.
- As far as safety is concerned, water that accumulates below the reinforcing bars, reduces the bond between the reinforcement and concrete.
- In the process of bleeding the accumulation of water creates a water voids and reduces bond between the aggregate and cement paste.
- Due to bleeding pumping ability of concrete is reduced.
- Increase in the water-cement ratio at the top.
- The accumulation of water at the top, results in delayed surface finishing.

The bleeding is not completely harmful if the rate of evaporation of water is equal to the rate of bleeding. Normal bleeding is quite good for properties of concrete as it enhances the workability of concrete. Bleeding replaces the water lost by evaporation and prevents the surface from drying quickly before it has attained sufficient strength to resist cracking.

Early bleeding when the concrete mass is fully plastic, may not cause much harm, because concrete being in a fully plastic condition, will get subsided and compacted. It is the delayed bleeding, when the concrete has lost its plasticity, which causes undue harm to the concrete. Controlled re-vibration may also be adopted to overcome the effect of bleeding.

- Steps in manufacturing of concrete

A good quality concrete is essentially a homogeneous mixture of cement, coarse and fine aggregates and water which consolidates into a hard mass due to chemical action between the cement and water. Each of the four constituents has a specific function. The coarser aggregate acts as a filler. The fine aggregate fills up the voids between the paste and the coarse aggregate. The cement in conjunction with water acts as a binder. The mobility of the mixture is aided by the cement paste, fines and nowadays, increasingly by the use of admixtures.

Most of the properties of the hardened concrete depend on the care exercised at every stage of the manufacture of concrete. A rational proportioning of the ingredients of concrete is the essence of the mix design. However, it may not guarantee of having achieved the objective of th e quality concrete work. The aim of quality control is to ensure the production of con crete of uniform strength from batch to batch. This requires some rules to be followed in the various stages of concrete production and are discussed as follows. The stages of concrete production are:

1. Batching or measureme nt of materials
2. Mixing
3. Transporting
4. Placing
5. Compacting
6. Curing
7. Finishing

Baching of Materials

For good quality co ncrete a proper and accurate quantity of all th e ingredients should be used. The aggregates, cement and water should be measured wit h an accuracy of � 3 per cent of batch quan tity and the admixtures by 5 per cent of the ba tch quantity. There are two prevalent meethods of batching materials, the volume batc hing and the weigh batching. The factors affecting the choice of batching method are the size of job, required production rate, a nd required standards of batching performance. For most important works weigh batch ing is recommended.

a) Volume Batching

b) Weigh Batching

Mixing

1. Hand Mixing
2. Machine Mixing

a) Tilting Mixers

b) Non-tilting Mixer

c) Reversing Drum Mixer

d) Pan-type or Stirring Mixer

e) Transit Mixer

Charging the Mixer and Mixing Time

The order of feeding the ingredients into the mixer is as follows:

About 25 per cent of water required for mixing is first introduced into the mixer drum to prevent any sticking of cement on the blades and bottom of the drum. Then the ingredients are discharged through the skip. In the skip the sequence of loading should be to add first half the coarse aggregate then half the fine aggregate and over this total cement and then the balance aggregates. After discharging the ingredients into the drum the balance water is introduced. The mixing time is counted from the instant complete water is fed into the mixer.

The speed of the mixers is generally 15 to 20 rpm. For proper mixing, the number of revolutions per minute required by the drum are 25 to 30. Time of mixing also depends on capacity of mixer and is given in Table 10.3.

Table 10.3 Time of Mixing

Capacity of Mixer	Minimum mixing time (minutes)	
(cum)	Natural aggregates	Manufactured aggregates
³ 3	2	2.5
2	1.5	2
£ 1	1.25	1.5

A poor quality of concrete is obtained if the mixing time is reduced. On the other hand if the mixing time is increased it is uneconomical. However, it is found that if the mixing time is increased to 2 minutes the compressive strength of concrete produced is enhanced and beyond this time the improvement in compressive strength is insignificant. A prolonged mixing may cause segregation. Also, due to longer mixing periods the water may get absorbed by the aggregates or evaporate resulting in loss of workability and strength.

Transporting

Concrete should be transported to the place of deposition at the earliest without the loss of homogeneity obtained at the time of mixing. A maximum of 2 hours from the time of mixing is permitted if trucks with agitator and 1 hour if trucks without agitators are used for transporting concrete. Also it should be ensured that segregation does not take place during transportation and placement. The methods adopted for transporting concrete depend upon the size and importance of the job, the distance of the deposition place from the mixing place, and the nature of the terrain. Some of the methods of transporting concrete are as below:

a. Mortar Pan
b. Wheel Barrow
c. Chutes
d. Dumper
e. Bucket and Ropeway
f. Belt conveyor
g. Skip and Hoist
h. Pumping

Placing

To achieve quality concrete it should be placed with utmost care securing the homogeneity achieved during mixing and the avoidance of segregation in transporting. Research has shown that a delayed placing of concrete results in a gain in ultimate compressive strength provided the concrete can be adequately compacted. For dry mixes in hot weather delay of half to one hour is allowed whereas for wet mixes in cold weather it may be several hours. The various situations in which concrete is placed are discussed below.

Foundations

Concrete foundations for walls and columns are provided below the ground surface. Before placing the concrete in the foundation all the loose earth, roots of trees etc., are removed. If the surface is found dry it is made wet so that earth does not absorb water from concrete. On the other hand if the foundation bed is wet the water and mud is removed and cement is sprinkled before placing concrete.

Beams, Columns, and Slabs

Before placing the concrete, the forms must be examined for correct alignment. They should be adequately rigid to withstand the weight of concrete and construction loads without undue deformation. Forms should be light enough to avoid any loss of mortar resulting in honeycombed concrete. The insides of the forms should be cleaned and oiled before use to avoid any sticking of concrete with the forms and making their stripping off difficult.

Concrete should not be dropped but placed in position to prevent segregation. It should be dropped vertically from as small height as possible. It should be placed at one point in the formwork and allowed to flow side ways to take care of honeycombing.

Laitance formation should be avoided. It can be checked by restricting thickness of layer of concrete by 150-300 mm for R.C.C work. Laitance, however, if formed must be removed before placing the next layer of concrete. Several such layers form a lift, provided they follow one another quickly enough to avoid cold joints. The surface of the previous lift is kept rough and all the laitance removed before placing the next lift.

The reinforcement should be checked for tightness and clean surface. The loose rust or scales if any, are removed by wire brush. Paint, oil or grease if found should be removed. The minimum cover for reinforcement should be checked before concreting.

Mass Concreting

When the concrete is to be laid in mass as for raft foundation, dam, bridge, pier etc., concrete is placed in layers of 350-450 mm thickness. Several such layers placed in quick succession form a lift. Before placing the concrete in the next lift, the surface of the previous lift is cleaned thoroughly with water jets and scrubbing by wire brush. In case of dams, sand blasting is done.

The laitance and loose materials are removed and cement slurry is applied. When the concrete is subjected to lateral thrust, *bond bars* or *bond stones* are provided to form a key between different layers.

Concreting Highways and Runways

Concrete is laid in bays for highway, runway, or floor slabs. First the ground on which concrete is to be laid is prepared and all the loose materials and grass etc., are removed. The earth is wetted and compacted. The subgrades over which concrete is to be laid should be properly compacted and damped to avoid any loss of moisture from concrete. Concrete is then laid in alternate bays. This allows the concrete to undergo sufficient shrinkage and cracks do not develop afterwards. Concrete is not placed in heap at one place and then dragged, instead it is placed in uniform thickness.

Concreting Underwater

Concrete may be placed underwater with the help of bottom dump buckets. The concrete is taken through the water in water- tight bucket. On reaching the place of deposition the bottom of the bucket is made to open and the concrete is dumped. In this process certain amount of cement is washed away causing a reduction in strength of concrete. Another way of concreting underwater is by filling cement bag with dry or semi-dry mix of cement and aggregates and lowering them to the place of deposition. The draw back of this method is that the concrete will be full of voids interspersed with purticible gunny bags.

The best method of placing concrete underwater is by the use of *termie* pipe. The concrete is poured into it through funnel. The bottom end of the pipe is closed with a thick ploythene sheet, with the bottom end of the pipe at the place of deposition. The concrete (slump 150-200 mm) is poured into funnel till the whole pipe is filled with concrete. The pipe is slightly lifted and given a jerk, the polythene sheet cover falls and concrete discharged. It should be ensured that the end of pipe remains inside the concrete so that water does not enter the pipe. The pipe is again filled with concrete through funnel and the process repeated till the concrete level comes above the water level. No compaction is required for underwater concrete as it gets compacted by the hydrostatic pressure of water. Concrete can also be placed underwater with the help of pipes and pumps.

Compaction

After concrete is placed at the desired location, the next step in the process of concrete production is its compaction. Compaction consolidates fresh concrete within the moulds or frameworks and around embedded parts and reinforcement steel. Considerable quantity of air is entrapped in concrete during its production and there is possible partial segregation also. Both of these adversely affect the quality of concrete. Compaction of the concrete is the process to get rid of the entrapped air and voids, elimination of segregation occurred and to form a homogeneous dense mass. It has been found that 5 per cent voids in hardened concrete reduce the strength by over 30 per cent and 10 per cent voids reduce the strength by over 50 per cent. Therefore, the density and consequently the strength and durability of concrete largely depend upon the degree of compaction. For maximum strength driest possible concrete should be compacted 100 per cent.

The voids increase the permeability of concrete. Loss of impermeability creates easy passage of moisture, oxygen, chlorides, and other aggressive chemicals into the concrete. This causes rusting of steel and spalling (disintegration) of concrete i.e., loss of durability. Easy entry of sulphates from the environment causes expansive reaction with the tricalcium aluminate (C_3A) present in cement. This causes disintegration of concrete and loss of durability. Entry of carbon dioxide causes carbonation of concrete i.e., loss of alkalinity of concrete or loss of the protective power that concrete gives to the reinforcement or other steel embedded in it. Once the carbonation depth exceeds the thickness of concrete cover to the embedded steel, steel becomes vulnerable to the attack of moisture. This expedites rusting of steel as the protective concrete cover remains no longer alkaline in nature.

Voids also reduce the contact between embedded steel and concrete. This results in loss of bond strength of reinforced concrete member and thus the member loses strength. Voids such as honeycombs and blowholes on the exposed surface produce visual blemish. Concrete surface is not good to look with all such blemishes. Concrete with smooth and perfect, surface finish not only looks good but is also stronger and more durable.

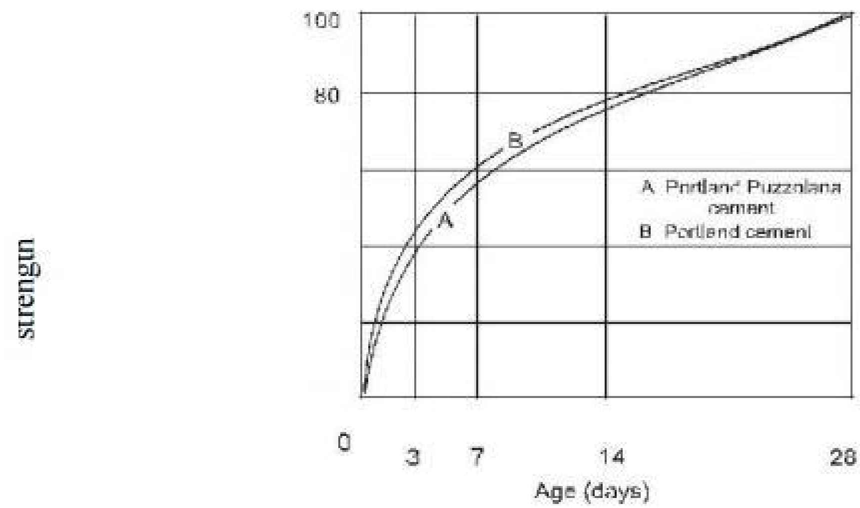
Compaction is achieved by imparting external work over the concrete to overcome the internal friction between the particles forming the concrete, between concrete and reinforcement and between concrete and forms and by reducing the air voids to a minimum. The compaction of concrete can be achieved by the following methods.

1. Hand Compaction
2. Compaction by Vibration
   a. Needle Vibrator:
   b. Formwork Vibrator
3. Compaction by Spinning
4. Compaction by Jolting
5. Compaction by Rolling

Curing

Cement gains strength and hardness because of the chemical action between cement and water. This chemical reaction requires moisture, favourable temperature and time referred to as the curing period. The variation of compressive strength with curing period is shown in Fig. 10.11 (a, b). Curing of freshly placed concrete is very important for optimum strength and durability. The major part of the strength in the initial period is contributed by the clinker compound C_3S and partly by C_2S, and is completed in about three weeks. The later strength contributed by C_2S is gradual and takes long time. As such sufficient water should be made available to concrete to allow it to gain full strength. *The process of keeping concrete damp for this purpose is known as curing*. The object is to prevent the loss of moisture from concrete due to evaporation or any other reason, supply additional moisture or heat and moisture to accelerate the gain of strength. Curing must be done for at least three weeks and in no case for less than ten days.

Approximately 14 litres of water is required to hydrate each bag of cement. Soon after the concrete is placed, the increase in strength is very rapid (3 to 7 days) and continues slowly thereafter for an indefinite period. Concrete moist cured for 7 days is about 50 per cent stronger than that which is exposed to dry air for the entire period. If the concrete is kept damp for one month, the strength is about double than that of concrete exposed only to dry air.



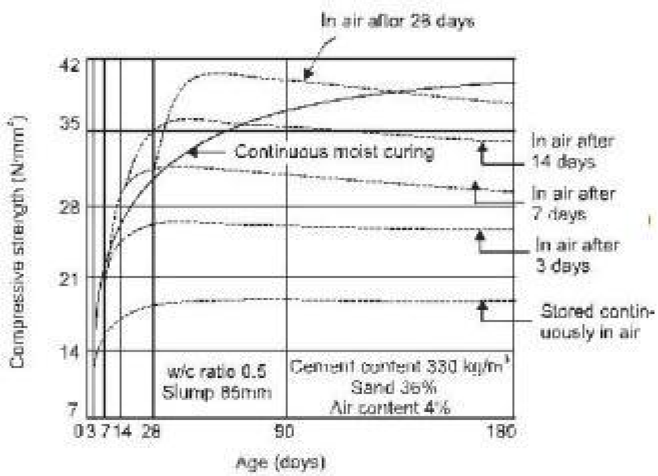


Fig.Development of Strength with Curing

Methods of Curing

Concrete may be kept moist by a number of ways. The methods consist in either supplying additional moisture to concrete during early hardening period by ponding, spraying, sprinkling, etc. or by preventing loss of moisture from concrete by sealing the surface of concrete by membrane formed by curing compounds. Following are some of the prevelent methods of curing.

1. Water Curing
2. Steam Curing
3. Curing by Infra Red Radiation:
4. Electrical Curing
5. Chemical Curing:

Finishing

Concrete is basically used because of its high compressive strength. However, the finish of the ultimate product is not that pleasant. In past couple of decades efforts have been made to develop surface finishes to give a better appearance to concrete surfaces and are as follows.

1. Formwork Finishes
2. Surface Treatments
3. Applied Finishes

❖ Quality of mixing water

Generally, quality of water for construction works are same as drinking water. This is to ensure that the water is reasonably free from such impurities as suspended solids, organic matter and dissolved salts, which may adversely affect the properties of the concrete, especially the setting, hardening, strength, durability, pit value, etc. The water shall be clean and shall not contain sugar, molasses or gur or their derivatives, or sewage, oils, organic substances. If the quality of water to be used for mixing is in doubt, cubes of 75 mm in cement mortar 1:3 mix with distilled water and with the water in question shall be made separately. The latter type of cubes should attain 90% of the 7 days' strength obtained in cubes with same quantity of distilled water. Alternatively, the water shall be tested in an approved Laboratory for its use in preparing concrete / mortar.

❖ Water/ Cement Ratio

- The **water–cement ratio** is the ratio of the weight of water to the weight of cement used in a concrete mix. A lower ratio leads to higher strength and durability, but may make the mix difficult to work with and form. Workability can be resolved with the use of plasticizers or super-plasticizers.

- Often, the ratio refers to the ratio of water to cementitious materials, w/cm. Cementitious materials include cement and supplementary cementitious materials such as fly ash, ground granulated blast-furnace slag, silica fume, rice husk ash and natural pozzolans. Supplementary cementitious materials are added to strengthen concrete.
- The notion of water–cement ratio was first developed by Duff A. Abrams and published in 1918. Refer to concrete slump test. The 1997 Uniform Building Code specifies a maximum of 0.5 ratio when concrete is exposed to freezing and thawing in a moist condition or to de-icing chemicals, and a maximum of 0.45 ratio for concrete in a severe or very severe sulfate condition.
- Concrete hardens as a result of the chemical reaction between cement and water (known as hydration, this produces heat and is called the heat of hydration). For every pound (or kilogram or any unit of weight) of cement, about 0.35 pounds (or 0.35 kg or corresponding unit) of water is needed to fully complete hydration reactions.[1]
- However, a mix with a ratio of 0.35 may not mix thoroughly, and may not flow well enough to be placed. More water is therefore used than is technically necessary to react with cement. Water–cement ratios of 0.40 to 0.60 are more typically used. For higher-strength concrete, lower ratios are used, along with a plasticizer to increase flowability.
- Too much water will result in segregation of the sand and aggregate components from the cement paste. Also, water that is not consumed by the hydration reaction may leave concrete as it hardens, resulting in microscopic pores (bleeding) that will reduce final strength of concrete. A mix with too much water will experience more shrinkage as excess water leaves, resulting in internal cracks and visible fractures (particularly around inside corners), which again will reduce the final strength.

❖ Abram's Law

Abrams' law (also called **Abrams' water-cement ratio law**)[1] is a concept in civil engineering. The law states the strength of a concrete mix is inversely related to the mass ratio of water to cement.[1][2] As the water content increases, the strength of concrete decreases.

Abrams' law is a special case of a general rule formulated empirically by Feret:

- S= A/B

where

S is the strength of concrete

A and B are constants

w/c is the water–cement ratio, which varies from 0.3 to 1.20

- **Gel Space Ration**

The ratio of volume occupied by hydrated cement paste to the aggregated volume of capillary pores and hydrated cement paste is known as gel/space ratio. It is denoted by r. Powers (1958) found that compressive strength of concrete is 34000 r^3 psi (234 r^3 MPa) and interestingly he found no influence of mix proportion of concrete and age of it on strength prediction. To realize the definition and significance of gel/space ratio it is required to discuss about volume of hydration product.

The total space available to occupy by productsof hydration is the summation of absolute volume of fresh cement and the volume of mixing water. Of these, if small loss of water under the contraction of the cement paste and that due to bleeding is ignored, the water consumed by chemical reaction with C_2S and C_3S was found to be 21 and 24 percent (very roughly) of the mass of two respective silicates.

If the final reaction of hydrate C_4AF is

$$C_4AF + 2\,Ca(OH)_2 + 10H \longrightarrow C_3AH_6 + C_3FH_6 \qquad ...(1)$$

The respective figures of C_3AF and C_3A are 37 and 40 percent. Equation (1) is also vary approximately due to our inadequate knowledge of stoichiometry of the hydration products and cannot be ascertained the amount of chemically combined water.

on-evaporable water determined under specific conditions is considered as 23% if anhydrous cement (measured by mass); in case of type II, moderate sulfate resistant cement, this value may be 18%. The specific gravity of hydration products of cement becomes such that the resulting volume is more than absolute volume of anhydrous cement.

Volume of hydration product > **Volume of anhydrate cement**

Volume of hydration product < **[Volume of dry cement] + [Non-evaporable water]**

Volume of hydration product = **[Volume of dry cement] +[Non-evaporable water]- 0.254 X [Non-evaporable water]**

Volume of hydration product = **[Volume of hydration product] + [Volume of dry cement] + (1-0.254)X [Non-evaporable water]**

The average value of specific gravity of hydration product in saturated structure, inclusive of pores available in the possible densest structure, is 2.16.

Here we are providing a demonstration of calculation of volume change during hydration.

Calculation of gel/space ratio for complete hydration

Let C = weight of cement in gm.

V_C = specific volume of cement = 0.319 ml/gm. W_O = volume of mixing water in ml.

Assuming that 1 ml. of cement on hydration will produce 2.06 ml of gel, Volume of gel = C x 0.319 x 2.06

Space available = C x 0.319 + W_O

\
$$\text{Gel/Space ratio} = x = \frac{\text{Volume of gel}}{\text{Space available}} = \frac{0.657\ C}{0.319\ C + W_O}$$

Calculation of gel/space ratio for partial hydration

Let a = Fraction of cement that has hydrated Volume of gel = C xa x 0.319 x 2.06

Total space available $C\ V_C\ a + W_O$

$\therefore$ Gel/space ratio = $x = \frac{2.06 \times 0.319 \times Ca}{0.319\,Ca + W_O}$.

Example: Calculate the gel/space ratio and the theoretical strength of a sample of concrete made with 500 gm. of cement with 0.5 water/cement ratio, on full hydration and at 60 per cent hydration.

Gel/space ratio on full hydration $= \frac{0.657\ C}{0.319\ C + W_O} = 0.802$ say 0.8

$\therefore$ Theoretical strength of concrete $= 240 \times (0.8)^3 = 123$ MPa Gel/space ratio for 60 percent hydration.

$$x = \frac{0.657\ C}{0.319\ Ca + W_O} = \frac{0.657 \times 500 \times 0.6}{0.319 \times 500 \times 0.6 + 250} = \frac{197.1}{345.7} = 0.57$$

Theoretical strength of concrete at 60 per cent hydration = 240 x (0.57^3) = 44.4 MPa

There is a lot of difference between the theoretical strength of concrete and actual strength of concrete. Actual strength of concrete is much lower than the theoretical strength estimated on the basis of molecular cohesion and surface energy of a solid assumed to be perfectly homogeneous and flawless. The actual reduction of strength is due to the presence of flaws. Griffith postulated his theory on the flaws in concrete. He explains that the flaws in concrete lead to a high stress concentrations in the material under load, so that a very high stress is reached in and around the flaws with the result that the material gets fractured around this flaw while the average stress on the material, taking the cross section of the material as a whole, remains comparatively low. The flaws vary in size. The high stress concentration takes place around a few of the larger flaws. This situation leads to failure of the material at a much lower stress intensity considering the whole process. Presence of bigger flaws brings down the actual strength to a much lower value than the theoretical strength.

❖ Maturity Concept

While dealing with curing and strength development, we have so far considered only the time aspect. It has been pointed out earlier that it is not only the time but also the temperature during the early period of hydration that influence the rate of gain of strength.

One of the methods to determine the strength of concrete is to find maturity of concrete. Maturity of concrete is defined as Summation of product of age and temperature (Curing).

Concrete Maturity = ∑ **(Time x Temperature)**

Hydration can take place at minimum of -10°C, below this water crystals (ice) do not react with cement.

Datum Temperature = -10°C

If Day Temperature = 15°C then

Curing temperature = 15-(-10)=25°C

Maturity of concrete after 28 days kept at 25°C is given as

Maturity = 28 x 24 x (25-(-10)) = 23520°C hr.

Concrete is fully matured when it is cured at 18°C till 28 days. For ordinary concrete maturity should not be less than 19800°C hr.

❖ Test on Fresh Concrete

1. They permit some estimation of the subsequent behaviour of the hardened concrete.

2. Changes in the properties of fresh concrete imply that the concrete mix is changing, so that some action can be taken if necessary.

Concrete is a composite material made from cement, aggregate, water, and admixtures. The variation of these components both in quality and quantity directly affects the resulting mix. When sampling fresh concrete for testing, it is important to take samples from various locations or several points during the discharge of the concrete. Samples should not have contacted forms or subgrade, and collection should be done in such a way that no segregation occurs.

- **Time of Setting** -- A penetration test, used to help regulate the times of mixing and transit, gauges the effectiveness of various set-controlling admixtures, and help plan finishing operations. The test is performed on the mortar faction, the amount of concrete passing a No. 4 sieve, of the concrete rodded into a container.
- **Air Content** -- These tests measure the total air content, entrained air plus entrapped air expressed in terms of the volume of concrete.
    - **Gravimetric Method** -- Compares the weight of a concrete containing air to that of a computed air-free concrete.
    - **Volumetric Method** -- Compares the volume of fresh concrete containing air with a volume of the same concrete after the air has be expelled by agitating the concrete under water. Difficult to measure in the field and required a large amount of physical effort.
    - **Pressure Method** -- The most common field measurement for air content. Compares the change in volume of a concrete under a given pressure. This change in volume is caused entirely by the compression of air in the concrete, both in the cement and the aggregate.

*** All these tests give no information about the spacing of the voids. They only measure the total air content of the concrete.

❖ Rapid Analysis of Fresh Concrete

There are a number of tests which separate the components of fresh concrete and test for a variety of mix properties; however, none are as yet accepted by ASTM. There are some tests that do not require separation of the components of the concrete:

- **Thermal Conductivity** -- Increase in water slows temperature rise.
- **Capacitance Test** -- Higher water content, increases dielectric constant.
- **Electrical Resistance** -- Electrical resistance of fresh concrete is inversely proportional to the water content.
- **Nuclear Methods** -- X-rays, gamma-rays, and neutron activation analysis can be used to measure the cement and water contents.

❖ **Relationship between Tensile and Compressive strength**

- The theoretical compressive strength of concrete is eight times larger than its tensile strength. This implies a fixed relation between the compressive and tensile strength of concrete. In fact there is a close relation but not a direct proportionality. The ratio of tensile to compressive strength is lower for higher compressive strengths.
- Experimental results also have shown that concrete in compression and tension (both direct tension and flexural tension) are closely related but the relationship is not of direct proportionality type. The ratio of tensile strength to compressive strength depends upon the strength of concrete. Thus higher the compressive strength, higher the tensile strength, but the rate of increase of tensile strength is of decreasing order. The tensile strength of concrete is more sensitive to improper curing than the compressive strength.

This may be due to the following two reasons:

(a) Formation of inferior quality gel due to improper curing.

(b) Development of more shrinkage cracks due to improper curing. The uses of pozzolanic materials have shown the increase in tensile strength.

The Central Road Research Institute Delhi has carried out extensive study for establishing the relation between tensile and compressive strength of concrete for the construction of concrete roads. Fig.13.7.

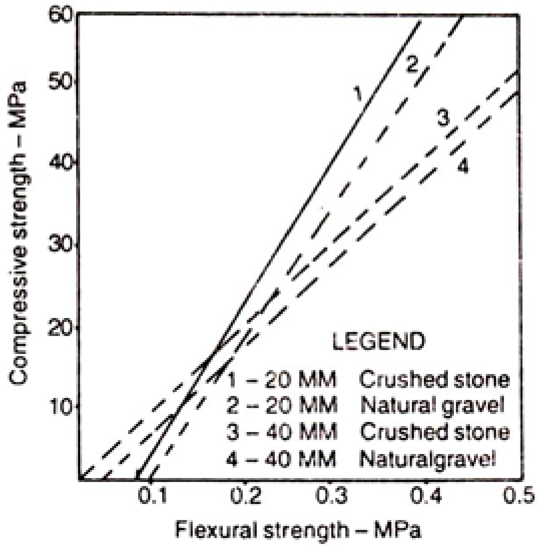


Fig. 13.7. Relation between flexural and compressive strength

On the basis of test data of the study, CRRI has suggested the following relation between flexural strength and compressive strength of concrete:

$y = 11\,x - 3.4$

where y is the compressive strength of concrete in MPa and x its flexural strength. This relation depends on the size of coarse aggregate. The strength is found to vary with the nature and size of aggregate.

The relation is reproduced below:

ADVERTISEMENTS:

The flexural strength of concrete was found to be 8 to 11% of the compressive strength of concrete of higher strength concrete of the order of 25 MPa (250 kg/cm^2) and 9 to 12.8% for concrete of strength less than 25 MPa (250 kg/cm^2) see Table 13.1:

Table 13.1. Flexural strength in % of compressive strength of concrete with different aggregates

S. No.	Compressive strength in MPa	Flexural strength as percentage of compressive strength percent			
		Gravel with max. size		Crushed stone with max. size	
		20 mm	40 mm	20 mm	40 mm
1.	49	8.7	—	7.7	—
2.	42	9.0	10.8	7.9	10.2
3.	35	9.3	10.9	8.2	10.3
4.	28	9.9	11.1	8.6	10.2
5.	21	10.8	11.3	9.3	10.3
6.	14	12.5	12.0	10.8	10.5
	Average	10.0	11.2	8.8	10.3

The ratio of flexural strength to compressive strength was found higher for 40 mm maximum size aggregate than that of 20 mm max sized aggregate. In general the ratio was found slightly higher for natural gravel than for crushed stone.

It has been observed that the flexure strength or modulus of rupture is obtained much lower by two point methods than central point loading as shown in Fig.13.8.

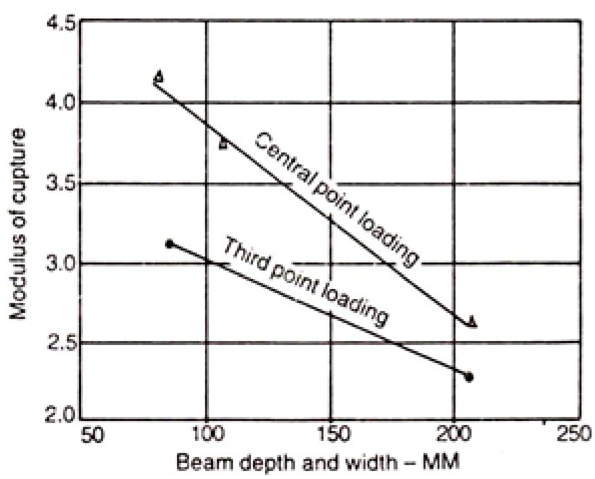


Fig. 13.8. Moduus of rupture of different sizes of beams subjected to central point and third point loading

The test can be performed as per IS 516-1959 or 1964 on a beam specimen of 10 x 10 x 50 cms within a span of 40 cms. The modulus of rupture is given by the relation.

$f_b = 2p \times a/bd^2$

where,

f_b = modulus of rupture

p = load applied on specimen in kg,

a = distance between the crack and the nearest support

b = width of beam in cms

d = depth of specimen at failure point in cms

The value of modulus of rupture varies from 11% to 23% of the compressive strength of the same concrete. The average value may be assumed as 15% of the compressive strength, the use of angular aggregate or rough textured aggregate results in higher modulus of rupture than smooth textured aggregates

Thus the modulus of rupture is higher than direct tensile strengths for the same concrete due to the following reasons:

1. Assumption of the shape of the stress block. In the calculation of modulus of rupture, it is assumed that stress is proportional to the distance from the neutral axis of the beam, while the shape of the actual stress block under loads nearing failure is known to be non-triangular, but parabolic. The modulus of rupture thus overestimates the tensile strength of concrete and gives a higher value than would be obtained in direct tensile test or splitting test.

2. The accidental eccentricity in a direct tensile test results in a lower apparent strength of the concrete.

3. Under direct tension the entire volume of specimen is subjected to the maximum stress, so that the probability of a weak element occurring is high.

4. The maximum fibre stress reached may be higher due to the fact that the propagation of a crack is blocked by less stressed material nearer to the neutral axis. However the actual values may vary depending on the properties of concrete.

Relation between compressive, tensile strength and modulus of rupture is shown in Table 13.2 below

Table 13.2. Showing variation in tensile strength obtained by different methods

S. No.	*Type of test*	*Mean strength in kg/cm^2*	*Standard deviation in kg/cm^2*	*Coefficient of variation*
1.	Direct tensile test	19.0	1.3	7
2.	Splitting test	27.9	1.4	5
3.	Modulus of rupture	41.7	2.5	6
4.	Compression cube test	412.3	14.3	3.5

Central Point and Two or Third Point Loading:

The Central Road Research Institute Delhi has carried out extensive study to find out the relation between central point loading and third point loading value of modulus of rupture. The ratio of span to depth of specimen was kept constant.

On the basis of experimental data, they established the following relation:

$x_1 = x_2 + 0.72$

Where,

x_1 = flexural strength of concrete in MPa under central point loading

x_2 = flexural strength of concrete in MPa under third point loading

During the study it was observed that central point loading gave higher average value of flexural strength than third point loading irrespective of the size of the specimen.

The higher strength obtained in central point loading may be due to the following facts:

The beam is subjected to the maximum stress at the predetermined point not necessarily the weakest.

2. The span to depth ratio of specimen was kept 4. The alteration in this ratio was found to alter the flexural strength. The change in the span to depth ratio by 1% induced 3% change in the flexural strength when tested by third point loading and 2.5% change when tested by central point loading. With the increase in span to depth ratio, the flexural strength was found to decrease.

3. The rate of stress application was found to influence the flexural strength to a great extent. If the rate of application of stress is increased from the standard rate of application of 0.7

MPa per minute, the flexural strength was found to increase upto 25%. The increase was found more with the leaner mixes.

There are many empirical relations between the tensile and compressive strength of concrete.

One of the most common relations is given by the following relation:

Tensile strength = K (compressive strength)^n.

The value of K may be taken as 6.2 for gravel and 10.4 for crushed aggregate. The average value for both may be taken as 8.3 and the value of n may vary from 0.5 to 0.75.

The I.S. 456-2000 has suggested the following relation between the compressive strength and flexural strength of concrete.

Flexural strength = $0.7\sqrt{f_{ck}}$

where f_{ck} is the compressive strength cylinder of concrete in MPa (N/mm^2).

The relationship between the compressive and tensile strengths of concrete suggested by Association of Portland cement laboratories is shown in Table 13.3. below:

Table 13.3. Relation between compressive and tensile strength of concrete

S. No.	*Compressive strength of cylinders in MPa*	*Strength ratio*		
		Modulus of rupture by third point loading to compressive strength	*Direct tensile strength to compressive strength*	*Direct tensile strength to modulus of rupture*
1.	7	0.23	0.11	0.48
2.	14	0.19	0.10	0.53
3.	21	0.16	0.09	0.57
4.	28	0.15	0.09	0.59
5.	35	0.14	0.08	0.59
6.	42	0.13	0.08	0.60
7.	49	0.12	0.07	0.61
8.	56	0.12	0.07	0.62
9.	63	0.11	0.07	0.63

❖ Factors Affecting the relation between tensile and compression strength

1) **Properties of Coarse Aggregate:**

- The properties of coarse aggregate affect the cracking of concrete very much. It has been observed that vertical cracking in a specimen subjected to uniaxial compression starts under a load equal to 50 to 75% of the ultimate load. The stress at which the cracks form depends to a great extent on the properties of coarse aggregate. It has been observed that concrete made from smooth surfaced gravel cracks at much lower stress than concrete made with rough and angular crushed rock aggregate. This may be due to mechanical bond and shape of the coarse aggregate.

- Further it has been observed that the properties of coarse aggregate affect tensile strength or the cracking load in compression more than the compressive strength of concrete The influence of the type of coarse aggregate on the strength of concrete varies in magnitude and depends on the water/ cement ratio of the mix. For water/cement ratio below 0.4, the use of crushed aggregate has resulted in increase in strength upto 38% than when gravel is used.
- With water/cement ratio above 0.5, the influence of water/cement ratio falls off and at 0.65 water/cement no difference in strength is observed. The properties of coarse aggregate have been found to have little effect on direct and splitting tensile strength, but flexural strength is found greater with the use of crushed and angular crushed rock aggregate than the rounded gravel.

2) **The Properties of Fine Aggregate:**

- The properties of fine aggregate also influence the ratio of tensile to compressive strength of concrete.
- The grading of aggregate also has been found to influence this ratio.

3) Effect of Moisture:

- The moisture condition of concrete influences the relation between the flexural and compressive strength. If one concrete is cured continuously in water and the other is curved wet and then stored in dry environment and tested. It is found that the dry concrete gave greater compressive strength than the continuously wet cured concrete. The direct and splitting tensile strengths are not affected in similar manner. However flexural strength of drying concrete is found lower than that of wet concrete. This may be due to the development of shrinkage cracks in the concrete.

4) Age of the Concrete at the Time of Testing:

- The increase in tensile strength after one month is slower than the compressive strength. Hence the age of specimen affects this ratio.

6. Methods of Testing:

Tensile strength is determined by the following methods:

- (a) Direct tension method.
- (b) Splitting tension method.
- (c) Flexural tension method.
- All the three methods give different results. The lowest value is given by the direct tension method. Thus values are given in order as direct tension < splitting tension < Flexural tension.

7. Size of Specimen:

- The smaller the size of test specimen, lesser volume of concrete is subjected to tensile stress, resulting in less chances of a weak element to be subjected to tensile stress and ultimately resulting in failure. On the other hand, larger the size of specimens, greater is the volume of concrete having greater chances of a weak element and ultimately resulting in failure, thus larger the specimen, greater the chances of failure.
- Secondly both the splitting and flexural test methods involve a non-uniform stress distribution which reduces the propagation of a crack, resulting in delay of ultimate failure on the other hand the stress distribution in the direct tension test is uniform, so that once a crack is formed, it can propagate quickly throughout the section of the specimen.

8. Effect of Inadequate Curing:

- Tensile strength of concrete is found more sensitive to the inadequate curing than compressive strength. This may be due to the non -uniform shrinkage of flexural test beams. As flexural test beams are very sensitive to shrinkage cracks and are very serious for the test.

❖ Curing test

Accelerated curing test:

Accelerated Curing Method is used to get early high compressive strength in concrete. This method is also used to find out 28 days compressive strength of concrete in 28 hours. (As per IS 9013-1978-Method of making, curing and determining compressive strength of accelerated cured concrete test specimens). Accelerated curing is useful in the prefabrication industry wherein high early age strength enables the removal of the formwork within 24 hours thereby reducing the cycle time resulting in cost saving benefits.The most commonly adopted curing techniques are **steam curing at atmospheric pressure, warm water curing, boiling water curing and autoclaving.**

Compressive Strength Test using Accelerated Curing

1. After the test specimens (whose 28 days strength to be determined) have been made, store it in moist air of at least 90 percent humidity for 23 hours $\pm$ 15 min. 2. Cover the specimens with flat steel cover plate to avoid distortion during the use. 3. Carefully and gently lower the specimens into the curing tank and shall remain totally immersed for a period of 3½ Hours $\pm$ 15 min. 4. The temperature of water in the curing tank shall be at boiling (100 ºC) when the specimens are placed. 5. After curing for 3 ½ hours in boil water, the specimen shall be carefully removed from the boiling water and cooled by immersing in cooling tank at 27 $\pm$2ºC for 2 hrs. 6. After cooling removethe specimens from the mould and tested for its accelerated compressive strength (Ra) in N/mm^2. **7. The 28 days can be found out using following formula.** Predicted 28 days compressive strength = R28 = 8.09 + 1.64 Ra, where Ra is accelerated compressive strength and R28 is predicted compressive strength at 28 days. **Read More:** Concrete Curing Methods for Different Types of Construction / Structures Methods of Curing Concrete Structures and their Comparisons Curing of High Performance Concrete -Methods and Duration of Curing Concrete Curing Time and Duration -Right Time of Curing Concrete Concrete Curing Methods for Different Types of Construction / Structures.

❖ Compressive Strength test of cube

- Compressive strength is the capacity of material or structure to resist or withstand under compression. The Compressive strength of a material is determined by the ability of the material to resist failure in the form cracks and fissure.
- In this test, the push force applied on the both faces of concrete specimen and the maximum compression that concrete bears without failure is noted.

- **Factors affecting compressive strength of concrete:-**

Coarse aggregate:-

Concrete is made homogenous by combining aggregates, cement, sand, water and various other admixtures. But even with proper mixing, there may arise some microcracks due to differences in thermal and mechanical properties of coarse aggregates and cement matrix, which leads to failure of concrete.

Concrete technologists came up with theoretical concepts regarding size of aggregates, which as the size of aggregate being the major contributor of compressive strength. So if the size of aggregate is increased, then it would lead increased compressive strength.

This theory was later discarded, as experiments proved that greater size of aggregates showed increased strength in initial phases but reduced exponentially.

The sole reason for this strength drop was due to the reduced surface area for bond strength between cement matrix and aggregates and weaker transition zone.

Air-entrainment:-

Air entrainment in concrete was one of the concepts developed by cold countries in order to prevent damages due to freezing and thawing. Later on, as experimentation's proved multidimensional benefits of air entrainment along with improved the workability of concrete at lower water/cement ratio.

- As the achievement of the desired workability at lower water content helped one to

  achieve concrete with the greater compressive strength which in turn, leads to light concrete with greater compressive strength.**Why do we test concrete for 7 days, 14 days & 28 days?:**

Concrete gains maximum strength at 28days. Since in construction sector great amount of capital is at stake, so instead of checking strength at 28 days we can check strength in terms of concrete strength psi at 7 and 14 days to predict the target strength of construction work.

From the below table it is clear that, Concrete gains 16 % of its strength within 24 hrs, whereas concrete gains 65% of the target strength by the time of 7 days of its casting.

Till 14 days concrete shows 90% of the target strength and thereafter the gain in strength slows down and it takes 28days to achieve 99% of strength.

We cant judge the strength of concrete until it becomes stable. And we also won't wait for 28 days to judge the concrete whether it suitable for construction or not to keep it balanced, concrete is tested at various intervals.

Age in Days	Percentage of Strength
1 Days	16%
3 Days	40%
7 Days	65%
14 Days	90%
21 Days	94%
28 Days	99%

Concrete Grade	Compressive strength in N/mm² at 3 days	Compressive strength in N/mm² at 7 days	Compressive strength in N/mm² at 14 days	Compressive strength in N/mm² at 28 days
M10	4	6.5	9	10
M15	6	9.75	13.5	15
M20	8	13	18	20
M25	10	16.25	22.5	25
M30	12	19.5	27	30
M35	14	22.75	31.5	35
M40	16	26	36	40
M45	18	29.25	40.5	45
M50	20	32.5	45	50

❖ Tensile Strength of Concrete

The **split tensile strength of concrete** is one of the basic and important properties which greatly affect the extent and size of cracking in structures. The concrete is not usually expected to resist the direct tension due to its low tensile strength and brittle nature.

However the determination of **split tensile strength of concrete** is necessary to determine the load at which the concrete members may crack. The test split tensile strength of concrete is very simple to perform and the most important fact is that it gives uniform results than the other tension tests like ring tension test and double punch test.

Apparatus Required for Split Tensile Strength of Concrete Test:-

- Compression testing machine
- Tamping rod
- Weighing device
- Tools and containers for mixing
- Tamper

IS Code for Split Tensile Strength Test of Concrete Mix:-

- IS: 456: 2000, Code for method of practice for plain and reinforced concrete
- IS: 5816: 1999, Method of test for split tensile strength of concrete

Advantage of Test for Split Tensile Strength of Concrete:-

- Same type and same specimens can also be used for compression test.
- The test split tensile strength of concrete is simple to perform and the most important fact is that it gives uniform results than the other tension tests like ring tension test and double punch test.

Procedure for Determination of Splitting Tensile Strength of Concrete:-

1. The specimens will be removed from the water after specified curing time and wiped out excess water from the surface. The dimensions of the specimens will be noted to the nearest 0.2m.
2. The bearing surfaces of the compression testing machine will be wiped clean. And any loose sand or other materials will be removed from the surfaces of the specimens which are to be in contact with the rollers.

3. Two bearings strips of nominal (1/8 inch i.e. 3.175 mm) thick plywood free of imperfections approximately (25 mm) wide and of length equal to or slightly longer than that of the specimen should be provided for each specimen.
4. These two bearing strips (plywood strips) are placed between the specimen and both the upper and lower bearing blocks of the strength testing machine. Also they can be placed between the specimen and the supplemental bars or plates.
5. Now draw diametric lines at each end of the specimen using a suitable device that will make sure that they are in the same axial plane.
6. One of the bearing strips (plywood strips) will be centered along the centre of the lower bearing block.
7. The specimen will be placed on the bearing strip (plywood strip) and aligned carefully so that the lines marked on the ends of the specimen will be vertical and cantered over the plywood strip.
8. The second plywood strip (bearing strip) will be placed lengthwise on the cylinder, cantered on the lines marked on the ends of the cylinder.
9. The load will be applied continuously and without shock, at a constant rate within, the range of 689 to 1380 kPa/min **splitting tensile stress** until failure of the specimen.

The maximum applied load indicated by the testing machine at failure will be recorded. Also the type of failure and appearance of fracture will be noted.

Formula for split tensile strength of concrete:-

Calculate the splitting tensile strength of the concrete specimens as follows:-

$$T = \frac{2P}{\Pi DL}$$

Where D is the Diameter (in meter), L is the length (in meter), P is the maximum applied load indicated by testing machine (in kN), T is the splitting tensile strength of concrete and $\prod$ = 22/7.

Finally the tensile strength of the specimen is calculated by using above formula, the tensile strength is determined.

(15) The shrinkage that takes place after the concrete has set and hardened is called drying shrinkage.

Drying Shrinkage:— We know that hydration of cement is an ever lasting process. Likewise drying shrinkage of concrete too is such when it is subjected to drying conditions.

This is similar to the drying mechanism of timber.

→ The loss of free water in hardened concrete does not result in dimensional changes.

→ But loss of water in gel pores causes volume changes.

→ Under drying conditions, the gel water is lost progressively.

According to IS 456-2000, total shrinkage of concrete depends upon

→ constituents of concrete
→ size of the member
→ Environmental conditions.
→ Total amount of water present in concrete at the mixing time

→ The total shrinkage strain may be taken as $\boxed{0.0003}$ IS: 1343.

→ cement paste shrinks more than mortar & mortar shrinks more than concrete.

→ Concrete with small size agg. shrinks more than large size agg.

→ The finer the gel, shrinkage is more.

→ High pressure steam cured ~~gel~~ concrete with low specific surface of gel — shrinks less than normally cured cement gel.

Factors affecting shrinkage:— ① Drying condition of the relative humidity at which concrete is kept.

→ If humidity is less, shrinkage is more

→ Magnitude of shrinkage increases with time.

(2) **Water/cemt ratio:** The richness of concrete has a significant impact on drying shrinkage. Refer graph (2)

Typical Values of shrinkage of mortar & concrete specimens @ relative humidity of 50% and 21°C.

Agg/cemt ratio	Shrinkage ($\times 10^{-6}$) after 6 months for w/c ratio of 0.4	0.5	0.6	0.7
3	800	1200	–	–
4	550	850	1050	–
5	400	600	750	850
6	300	400	550	650
7	200	300	400	500

From the above table, it can be seen that

(1) As w/c ratio increases, drying shrinkage increases.

(2) As aggreage quantity increase in concrete/mortar, the shrikage decreases.

(3) **Type of aggregate:** The quantity of aggregate alongwith quality (size, E value) influence the shrinkage value.

Harder aggregates results in lesser total drying shrinkage
Softer " " higher " "

As drying shrinkage is an inherent property of concrete, measures can be taken to reduce the shrinkage. But is is one of the most detrimental properties of concrete.

(4) The restraining effect of agg. & reinforcement causes high internal stresses which induces internal micro cracks which impairs structural integrity & durability of concrete.

(5) Moisture loss occurs at the surface of the concrete when. The internal moisture may not move to the surface at the same rate of drying, because of which moisture gradient is set up which results in differential stresses & induces cracks.

→ The shrinkage increases with the addition of $CaCl_2$ i.e. admixtures & reduces with lime replacement.

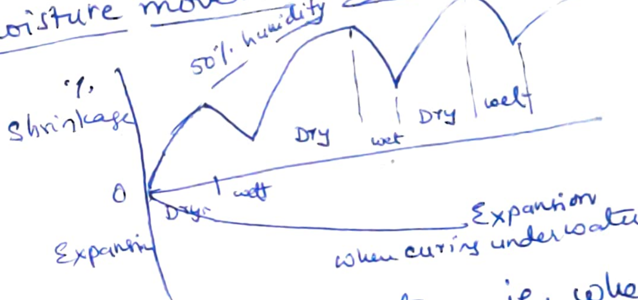
→ Size & thickness of the specimen :- As drying takes place at the surface of the concrete, the magnitude of shrinkage varies considerably with the size & thickness of the specimen

→ Shrinkage decreases with increase in the size of the member.

→ Rapid hardening cement shrinks little more than others.

Moisture Movement :- Concrete shrinks when allowed to dry in air with low humidity & swells when kept at 100% relative humidity or when placed in water.

Just as drying shrinkage is an everending process, swelling too occurs when subjected to wet conditions. The phenomenon of drying shrinkage is not a reversible one as only partial swelling will occur for concrete. This property of swelling & drying in accordance with the condition is called moisture movement in concrete.



Autogeneous shrinkage :- In a conservative system, i.e. where no moisture movement to or from the paste is permitted, & temp. is kept constant some shrinkage may occur. This type of shrinkage of a conservative system is called Autogeneous shrinkage.

This is of minor concern. The magnitude of autogeneous shrinkage is in the order of about 100×10^{-6}.

Carbonation Shrinkage :- CO_2 present in the atmosphere reacts in the presence of water with hydrated cement. Calcium hydroxide $Ca(OH_2)$ gets converted to calcium carbonate $(CaCO_3)$ & also some other cement compounds are decomposed.

Such a complete decomposition of calcium compounds in hydrated cement happens even at low pressure of CO_2 in normal atmosphere.

The rate of penetration of CO_2 depends also on the moisture content of concrete & relative humidity of medium.

Carbonation increases the wt. of concrete

Carbonation of concrete also results in increased strength & reduced permeability. Because the water released by carbonation promotes the hydration process and also $CaCO_3$ reduces the voids within the cement paste.

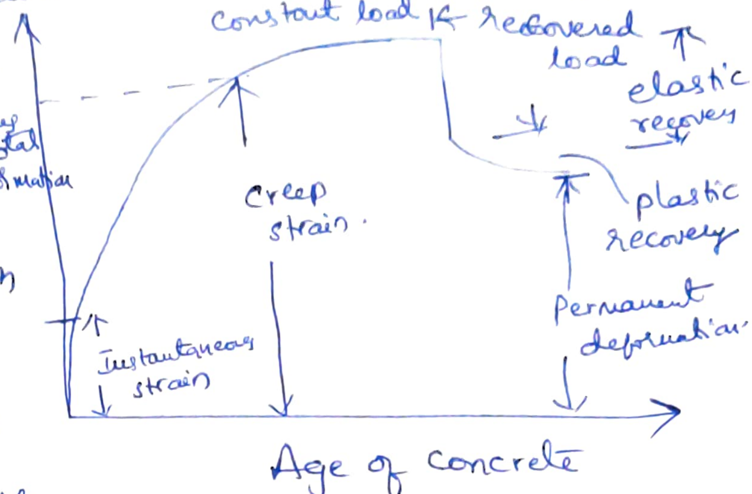
→ Carbonation reduces the alkalinity of concrete which gives a protective coating to the reinforcement against rusting. If depth of carbonation reaches upto steel, the steel is liable to corrode.

Thermal Shrinkage: Changes in volume of concrete may also occur due to temp. decrement. when the temp. goes below the ambient temp. shrinkage may occur as for other materials Ex. Roof slab / pavement is subjected to expansion during the day & undergoes thermal shrinkage during nights. Lack of durability of concrete is due to volume changes in Concrete. Volume changes cause cracks which inturn increase the permeability.

Coefficient of thermal expansion is defined as the change in unit length / ° change of temperature.

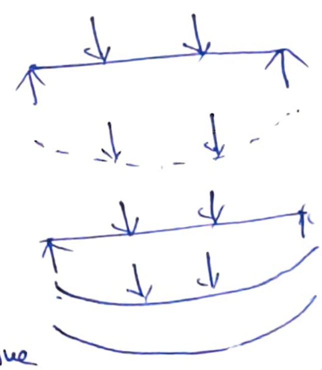
Creep: The increase of strain in concrete with time under sustained (stable) stress is termed as creep. This is also known as plastic flow or time yield. It can be defined as the elastic & long term deformation of concrete under a continuous load. The rate of creep decreases with time & creep strains at 5 years are taken as terminal values.

There are different strains,



1. Elastic strain: (Instantaneous strain)
The strain which occurs immediately after the application of load

2. As the load is kept on specimen for a long & considerable time, the strain which occurs is called creep strain.



Creep is time dependent component of strain.

$$\text{creep coefficient } (\theta) = \frac{\text{creep strain at time}}{\text{Instantaneous strain}}$$

Creep depends upon temperature, time, intensity of load

→ The stress-strain relationship of concrete is not linear but a curved one. The degree of curvature of p-ε curve depends mostly on intensity of stress & time for which load is acting. The gradual increase in strain without increase in stress with the time is due to creep.

→ All materials undergo creep but concrete creeps significantly at all stresses & for a long time.

The creep of concrete is approximately a linear function of stress upto 30% to 40% of its strength.

→ Compared to other crystalline materials, the creep in concrete is much greater except for metals in the final stage of yield & failure.

→ Hence this is considered as an isolated rheological phenomena.

→ As concrete is a two phase material, the deformation characteristics depend upon cement paste, aggregate & strength of concrete etc.

→ The formation of gel & the state of existence of water are the significant characteristic factors for deformation of concrete.

Gel provides rigidity & chemical bonding by force of ~~ag~~ attraction between particles. Water can exist as combined water, gel water & capillary water.

→ The conglomeration of all the above with enclosed water filled voids provide the sliding action like glacier movement in seas which is responsible for creep.

→ Finally, creep takes place only under sustained stress. As time passes, the gel, adsorbed layer, water in gel pores and capillary pores yields, flows & readjusts itself which is known as creep in concrete.

Measurement of Creep:- creep is measured by change in strain with time when the specimen is subjected to a constant stress.

It is found that creep decreases as time passes on. If creep after 1 year is taken as unity, then average creep value at later ages are

1.14 — 2 years
1.20 after 5 years
1.26 after 10 years
1.33 after 20 years
1.36 after 30 years.

According to Ross, ultimate creep

$$C = \frac{t}{a+bt}$$

t - time under load
a, b constants.

Specific creep is defined as the creep strain / unit stress.

Factors affecting creep:-

a) Influence of aggregates:- Paste phase & aggregate phase

It is the paste phase which undergoes creep. Aggregates tend to creep very little. They provide restraining effect on the magnitude of creep. If the aggregate is strong then creep will be less. Also if the Mod. of elasticity of ~~concrete~~ aggregate is more less will be the creep. Light wt. aggregates shows substantially higher creep than normal weight aggregates.

Influence of mix proportions:- The amount of paste content & structure is one of the most important factors influencing creep.

A poorer paste structure undergoes higher creep.

∴ Creep increases with increase in w/c ratio.

Creep is inversely proportional to strength of concrete.

Influence of Age:- The magnitude of creep depends upon age at which the concrete is loaded. This is because of the gel quality that is produced. Younger gel under load being not so strong, creeps more.

$$\text{Creep Coefficient} = \frac{\text{Ultimate creep strain at the age of loading}}{\text{Elastic strain}}$$

Ultimate creep can be found from the above eqn, if creep coefficient is known. As per IS-456-2000,

Age at loading	Value of creep coefficient
7 days	2.2
28 days	1.6
1 year	1.1

Admixtures Accelerators are also responsible for causing creep in concrete.

Effects of creep:- The magnitude of creep is dependent mainly time & level of stress.

- → In RC beams, creep increases the deflection with time.
- → In RC columns due to compressive load elastic deformation takes place. Concrete creeps & deforms. As concrete alone cannot deform, the stress in concrete is transferred to steel. Due to this both the materials will develop full strength.
- → But in eccentrically loaded columns, creep increases the deflection & can lead to buckling.
- → In case of statically indeterminate structures creep may releive stress concentration induced by shrinkage, temperature changes or support settlement.
- → In case of PSC, creep reduces the prestress & provision is made for the loss of prestress in the design of PSC structures.

natural frequency. Either resonant frequency through the specimen is found or pulse velocity travelling through concrete is found. Using the above parameters we have

$$\boxed{E_d = K n^2 L^2 \rho}$$

where

E_d - Dynamic mod. of elasticity

K - a constant, n - Resonant ~~velocity~~ frequency

L - Length of the specimen

ρ - density of concrete.

If 'L' is in mm and ρ in kg/m^3

$$\boxed{E_d = 4 \times 10^{-15} n^2 L^2 \rho} \text{ GPa}$$

The $E_{concrete}$ value found by method of velocity of sound / frequency of sound is termed as dynamic modulus of elasticity and it is higher than static method E_c. since it is unaffected by creep.

The creep does not also significantly effect the initial tangent modulus in the static method. Hence both values of initial tangent modulus & dynamic mod. have found to agree with each other.

Approx. relationship is

$$\boxed{E_c = 1.25 \underbrace{E_d}_{\text{Dynamic mod.}} - 19}, \text{ GN}/m^2.$$

Static modulus

For light wt. concrete, $\boxed{E_c = 1.04 E_d - 4.1}$.

The above relations do not hold good for rich concrete mixes where cement content $> 500 \text{ kg}/m^3$.

Poisson's Ratio :- This is the ratio of lateral strain to lineal strain & is denoted by 'μ'.

→ for normal concrete 'μ' lies betn 0.15 to 0.20 when actually determined by strain measurements.

→ By using pulse velocity & fundamental resonant frequency of longitudinal vibration of concrete beam too, 'μ' can be found.

$$\frac{(1-\mu)}{(1+\mu)(1-2\mu)} = \left(\frac{V^2}{2nL}\right)^2$$

V - pulse Velocity in mm/sec

n - Resonant frequency (Hz)

L - beam length in mm.

→ The value of 'μ' by dynamic method lies betn 0.2 - 0.24.

→ Dynamic mod. of elasticity 'Ed' too can be found as below.

$$Ed = \frac{\rho V^2 (1+\mu)(1-2\mu)}{(1-\mu)}$$

Shrinkage :- It is the volumetric change in concrete either induced or autogeneous. This is one of the detrimental properties of concrete which affects the long-term durability & strength. This causes unsightly cracks in concrete. The volume change also occurs due to

1. thermal properties of aggregates & concrete
2. Alkali aggregate reaction
3. sulphate action.

Shrinkage is a factor responsible for cracks in pavements & floors. Actually it is difficult to make a concrete does not shrink & crack. But a little control on magnitude may be exercised.

As it is an inherent property of concrete, unless the types of shrinkage, the causes, the factors affecting shrinkage are thoroughly understood, we cannot control & limit the shrinkage in the concrete.

1. Plastic shrinkage
2. Drying shrinkage
3. Autogeneous shrinkage
4. carbonation shrinkage
5. Thermal shrinkage.

Plastic Shrinkage :- comes into play soon after the concrete is placed in the forms while it is still in fresh state.

Reasons :- 1) Loss of water by evaporation from the surface of concrete

2) Absorption of water from aggregate / subgrade

→ The loss of water results in reduction in volume which causes subsidence due to which cracks may be appear at the surface or internally around the aggregate & reinforcement.

→ In case of floors and pavements where depth of concrete is less and a large surface area is exposed to hot sun & drying wind the surface dries very fast which results in plastic shrinkage.

→ Due to usage of higher w/c ratio, the extra water accumulates at the surface of concrete & after it gets dried out, concrete surface cracks due to plastic shrinkage.

→ Unintended vibration or yielding of formwork when the concrete is still in the plastic state too cause cracks.

→ Richer concrete mix with heavy amount of cement paste undergoes ~~too~~ greater plastic shrinkage.

Hence the causes are
1. higher w/c ratio
2. Badly proportioned concrete
3. Rapid drying
4. greater bleeding
5. unintentional vibration etc.

Remedial Measures:

→ By reducing rapid loss of water from surface.

→ Cover the surface with polyethylene sheets immediately after finishing operation.

→ By monomolecular coatings by fog spray to keep the surface moist

→ Working at night times.

→ Revibrating concrete in a controlled manner effectively reduces the shrinkage cracks.

→ Use of small qty of aluminium powder spread too will reduce shrinkage cracks.

→ Use of expansive cement / shrinkage compensating cement controls the shrinkage of concrete.

→ Avoidance of high slump concrete, higher sand quantity, higher air entraining should be discouraged.

Drying Shrinkage :- We know that hydration of cement is an ever lasting process. Likewise drying shrinkage of concrete too is such when it is subjected to drying conditions.

This is similar to the drying mechanism of timber

→ The loss of free water in hardened concrete does not result in dimensional changes.

→ But loss of water in gel pores causes volume changes.

→ Under drying conditions, the gel water is lost progressively.

According to IS 456-2000, total shrinkage of concrete depends upon

→ constituents of concrete

→ size of the member

→ Environmental conditions.

→ Total amount of water present in concrete at the mixing time

→ The total shrinkage strain may be taken as $\boxed{0.0003}$ IS: 1343.

→ cement paste shrinks more than mortar & mortar shrinks more than concrete.

→ Concrete with small size agg. shrinks more than large size agg.

→ The finer the gel, shrinkage is more.

→ High pressure steam cured ~~gel~~ concrete with low specific surface of gel — shrinks less than normally cured cement gel.

Factors affecting shrinkage :- ① Drying condition of the relative humidity at which concrete is kept.

→ If humidity is less, shrinkage is more

→ Magnitude of shrinkage increases with time.

ॐ

UNIT-V

Concrete Mix Design

One of the ultimate aims of studying various properties of constituent materials of concrete, plastic concrete & hardened concrete is to enable the technologist to design a concrete mix for a particular strength & durability.

→ As concrete contains different materials with various varying properties this task is not that simple.
→ The site conditions prevailing at work,
→ The exposure of concrete to prevailing condition,
→ Degree of supervision etc. need to be taken in to account.

One should know/ assess the effect of plastic condition onto the final hardened quality of concrete

→ The structural engineers stipulate some minimum strength and the concrete technologist should design the concrete mix considering the properties of materials used at site, prevailing site conditions, degree of supervision available to achieve that min. strength.
→ The site engineer is needed to closely follow the specifications. Sometimes slight adjustments too may become unavoidable at site. He is required to make trial specimens to assess the required strength.

Mix Design can be defined as the process of selecting the suitable ingredients of concrete & their proportions in order to produce a concrete of certain minimum strength and durability keeping in consideration the economy.

Variables in proportioning: With the given material, the four variables factors to be considered in connection with mix design of concrete of specified strength.

1) W/c ratio
2) Cement content & cement-aggregate ratio
3) Gradation of aggregate
4) Consistency.

→ W/c ratio expresses the dilution of cement paste.
→ Gradation of aggregate, the place where concrete is to be placed looks at slump of concrete.

Shallow sections - very low slump } 25-75 mm
Mass concrete, lightly reinforced

→ Heavily reinforced sections, thin sections } - 50-100 mm

→ The cement paste should fill the voids between fine & coarse aggregates & should bind them properly.

→ Excess paste is not only uneconomical, greater drying shrinkage, susceptibility of percolation of water & attack by chemicals & weathering action. To avoid these problems proper grading of aggregates is needed.

Various Methods of Proportioning: —

① Arbitrary method
2) Fineness Modulus method
3) Maximum Density "
4) Surface area "
5) IRC 44
6) High Strength Concrete mix Design
7) Road Note 4 method
⑧ ACI Committee method
⑨ DoE "
⑩ Pumpable concrete "
⑪ IS code method.
IS-10262-2009.

Statistical Quality control of concrete.

The concrete production, though the proportions are specified for constituent materials may not be at an even pace. There exists variations both in materials & in construction methods. These result in variations in results regarding strength from batch to batch or even in the same batch.

→ Hence it becomes difficult to assess the final strength of concrete mix.

→ We have to resort to sample tests as we can't go for more & more no. of destructive tests.

→ If on hand information well before is not known regarding strength, we cannot discard the structure

→ The basis of acceptance of a sample is that a reasonable control of concrete work may be provided by ensuring that the probability of test results falling below the design strength is not more than a specific tolerance level.

→ Compressive strength test cubes are cast while the work is proceeding, exhibit variations. If a no. of cube test results are plotted on histogram, the results are found to follow a bell shaped curve called the 'Normal distribution Curve'.

Common Terminologies used in the statistical quality control of concrete are as below:-

① Mean Strength: $\bar{x}$ = $\dfrac{\text{Average strength}}{\text{No. of cube specimens}}$ = $\dfrac{\Sigma x}{n}$

② Variance:- This is the measure of variability / difference between any single data under consideration & mean strength. $(x-\bar{x})$

③ Standard Deviation: This is the root mean square deviation of all the results. $\boxed{s \text{ or } \sigma}$

$$\sigma = \sqrt{\frac{\Sigma (x-\bar{x})^2}{n-1}}$$

σ – standard deviation
n – no. of observations of cube tests
x – particular value of observation
$\bar{x}$ – mean strength

Standard deviation increases with increasing variance. The characteristics of the normal distribution curve are fixed by the average value $(\bar{x})$ and the standard deviation (σ).

The spread along x-direction is governed by standard deviation.

The vertical ht. of curve is fixed by mean value.

Coefficient of Variation:- It is an alternate method to express the variation of results, which is non dimensional.

$$V = \frac{\text{Standard Deviation}}{\text{Arithmatic mean}} \times 100$$

$$= \sigma/\bar{x} \times 100$$

Relation between Average Design Strength & Specified minimum Strength.

The specified minimum strength will be stipulated by the site engineer. (as M_{25}, M_{30} ...)

The concrete mix design should be such that the average design strength should always be greater than min. strength.

→ The average design strength which the mix designer should aim at depends upon quality control exercised at the time of making concrete.

→ The increased value of Standard deviation & coefficient of variation indicate lesser degree of control in the making of concrete.

→ The average design strength

$$S_{av} = S_{min} + K\sigma$$

where S_{min} = Minimum required strength at site.

K = Himsworth Constant

σ = Standard Deviation.

Value for 'K' - Himsworth Constant

% of results allowed to fall below the minimum	Value of K
	3.09
0.1	2.50
0.6	2.33
1.0	1.96
2.5	1.50
6.6	1.00
16.00	

If coefficient of variation, v is used,

$$S_{ave} = \frac{S_{min}}{1 - \frac{kv}{100}}$$

IS concrete mix proportioning:

In 1982, the IS code of Concrete mix design was first introduced (IS 10262-1982). During the revision of IS 456-2000, this code was amended and released as IS 10262-2000. Now we have IS 10262-2009 for concrete mix designing.

Data required:

1. Grade of concrete
2. Max. size of aggregate
3. Minimum cement content
4. max. w/c ratio
5. workability in terms of slump.
6. Exposure conditions
7. max. temp. at the pouring point,
8. Grading zone of fine aggregate
9. Type of agg.
10. Max. cement content
11. Admixtures to be used
12. Sp. gr. of agg & cement.

Target Mean strength:— (f'_{ck}) The characteristic cube comp. strength of concrete required at the site of construction will be specified by the construction/site engineer. (f

But the concrete mix should be designed for higher strength than specified one.

It is assumed that not more than 5% of the site results are lesser than the characteristic strgth specified; the target mean strength

$f'_{ck} = f_{ck} + t \times s$

t – Tolerance factor
s - standard deviation.

Grade of Concrete	Assumed standard deviation N/mm^2
M10, M 15	3.5
M 20, M 25	4.0
M 30, M 35, M 40	5.00
M 45 – 60	5.0

Value of tolerances

Tol. level / No. of sample	1 in 15
	1.65
10	1.58
20	1.31
30	

Selection of water Cement Ratio:- The w/c ratio required actually for a project in particular should be found out by large no. of laboratory trials or at site using the actual type of aggregate and other materials which establishes the relationship between strength & w/c ratio.

In the recommended guidelines for concrete design mix of 10262-~~2000~~ 1882, w/c ratio was selected from ABCDEF curves drawn relation strgth & w/c ratio. This method was very uneconomical

Table 9.22. Environmental Exposure Conditions (IS 456 of 2000)

Environment	Exposure Conditions
Mild	Concrete surfaces protected against weather or aggressive conditions except those situated in coastal areas
Moderate	Concrete surfaces sheltered from severe rain or freezing whilst wet Concrete exposed to condensation and rain. Concrete continuously under water. Concrete in contact or buried under non-aggressive soil/ ground water.
Severe	Concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing whilst wet or severe condensation. Concrete Completely immersed in Sea water.
Very Severe	Concrete surfaces exposed to sea water spray, corrosive fumes or severe freezing conditions whilst wet. Concrete in contact or buried under aggressive subsoil/ground water. Concrete exposed to coastal environment
Extreme	Surface of members in tidal zone, members in dired contact with liquid/solid aggressive chemicals

9.40. Maximum Cement Content

Cement content not including fly ash and ground granulated blast furnace slag in excess of 450 kg/m^3 should not be used unless special consideration has been given in design to the increased risk of cracking due to drying shrinkage in thin sections, or to early thermal cracking and to the increased risk of damage due to alkali silica reaction.

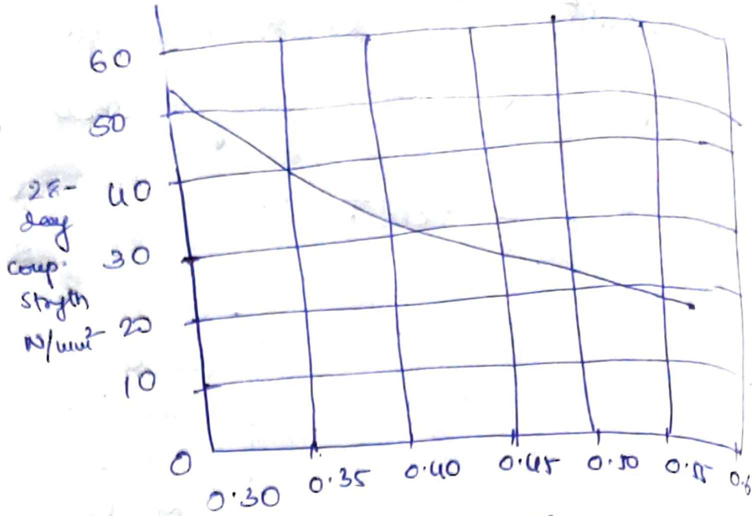
Table 9.23. Minimum Cement Content, Maximum W/C Ratio and Minimum Grade of Concrete for Different Exposures with Normal Weight Aggregates of 20 mm Nominal Maximum size. IS 456 : 2000

Sl. No.	Exposure	Plain Concrete			Reinforced Concrete		
		Minimum cement contents kg/m^3	Maximum Free W/C ratio	Minimum Grade of concrete	Minimum Cement Content kg/m^3	Maximum Free W/C ratio	Minimum Grade of Concrete
1.	Mild	220	0.60	–	300	0.55	M 20
2.	Moderate	240	0.60	M 15	300	0.50	M 25
3.	Severe	250	0.50	M 20	320	0.45	M 30
4.	Very Severe	260	0.45	M 20	340	0.45	M 35
5.	Extreme	280	0.40	M 25	360	0.40	M 40

Notes: (1) Cement content prescribed in this table is irrespective of the grade of cement and it is inclusive of all supplementary cementitious materials. The additions of all supplementary cementitious materials may be taken into account in the concrete composition with respect to the cement content and W/C ratio if the suitability is established and as long as the maximum amounts taken into account do not exceed the limit prescribed in relevant codes.

(2) Minimum grade for plain concrete under mild exposure condition is not specified.

The w/c ratio Vs strength in a generalised relation is shown.



<u>Selection</u> of <u>water Content</u>:

The qty of max. mixing water/ unit vol. of concrete is given in table 11.23.

Max. water content / m³ of concrete for nominal max. size of aggregate.

Sl.No	Nominal max. size of aggregates	Maximum water content (Kg)
1	10 mm	208
2	20 mm	186
3	40 mm	165

→ The water suggested is for angular coarse aggregate and for 25-50 mm slump range.

→ Water can be <u>reduced</u> by <u>10 kg</u> for sub angular aggregates, 20 kg for gravel & 25 kg for rounded gravel.

→ For every change in slump of 25 mm increase water has to be increased by 3%.

→ Plasticiser use reduces water content by 10%.

→ Super plasticizer use reduces water content by 30%.

→ The water content mentioned above is corresponding to saturated surface ...

Estimate of proportion : Coarse aggregate

Approx. CA volume is given below for a w/c ratio of 0.5. This aggregate volume may be adjusted for other w/c ratios as shown below.

→ For every decrease in w/c ratio by 0.05, the CA volume to be increased by 1% to reduce sand content.

→ For every increase in w/c ratio by 0.05, the CA volume was be decreased by 1% to increase the sand content.

→ For pupable concrete / tremie concreting it may be desirable to reduce the CA content by about 10%.

Vol. of CA /unit volume of total aggregate for diff. zones of FA for w/c ratio of 0.5

Sl. No.	Nominal max. size of agg (mm)	Vol. of CA/unit vol. of Total agg. for different zones of FA			
		Zone IV	III	II	I
1	10	0.5	0.48	0.46	0.44
2	20	0.66	0.64	0.62	0.60
3	40	0.75	0.73	0.71	0.69

Estimate of FA proportion

FA = (1 − CA proportion)

MODULE 6

Syllabus:

Special concretes - Lightweight concrete- description of various types - High strength concrete - Self compacting concrete -Roller compacted concrete – Ready mixed concrete – Fibre reinforced concrete - polymer concrete

Special processes and technology for particular types of structure - Sprayed concrete; underwater concrete, mass concrete; slip form construction, Prefabrication technology

LIGHT WEIGHT CONCRETE

Due to the high self-weight of concrete, density of normal concrete is the order of 2200-2600 kg/m^3. The heavy self-weight will make it to some extent an uneconomical structural material. Attempts have been made in the past to reduce the weight of concrete to increase the efficiency of concrete as a structural material.

The light weight concrete is a concrete whose density varies from 300 to 1850 kg/m^3. The following are the **advantages** of light weight concrete.

1. It helps in the **reduction of dead load** as its density is in the range 300 to 1850kg/ m^3
2. It **reduces the foundation cost** and **increases the number of floors** of buildings
3. It has **lower haulage and handling cost**
4. In the framed structure, the beam and the columns have to carry loads of floors and walls. If floors and walls are made up of light weight concrete then it will result in considerable **economy.**
5. The most important characteristic of light weight concrete is relatively **low thermal conductivity,** a property which improves with decreasing density in extreme climatic condition also in case of a building whose air conditioning is to be installed. The use of light weight concrete with low thermal conductivity will result in thermal comfort.
6. It is **durable**

Classification of LWC

It is convenient to classify the various types of lightweight concrete by their method of production. These are:

1. By using porous lightweight aggregate of low apparent specific gravity, i.e. lower than 2.6. This type of concrete is known as **light weight aggregate concrete**.
2. By introducing large voids within the concrete or mortar mass; these voids should be clearly distinguished from extremely fine voids produced by air entrainment. This type of concrete is known as **aerated, cellular, foamed or gas concrete**.
3. By omitting the fine aggregate from the mix so that a large number of interstitial voids are present; normal weight coarse aggregate is generally used. This concrete is known as **no-fines concrete.**

The decrease in density of the concrete in each method is obtained by the presence of voids, either in the aggregate or in the mortar or in the interstices between coarse aggregate particles. The presence of these voids reduces the strength of light weight concrete compared with ordinary, normal weight concrete but in many applications high strength is not essential.

Disadvantages:

- It is not highly resistant to abrasion
- Lightweight concrete is more expensive than ordinary concrete
- Mixing, handling and placing require more care and attention than ordinary concrete

For many purposes the advantage of light weight concrete outweigh its disadvantages, and there is a continuing world-wide trend towards more light weight concrete.

Manufacture of LWC:

LWC can be manufactured by the following three methods:

i) By using light weight Aggregate
ii) By introduction of gas or air bubbles in the mortar
iii) By omission of sand fraction from the aggregate.

Applications of LWC:

1. Pre-stressed concrete,
2. High-rise buildings
3. Shell roofs.

LIGHT WEIGHT AGGREGATES

Light weight aggregate is a relatively new material. For the same crushing strength, the density of concrete made with such an aggregate can be as much as 35 per cent lower than the normal weight concrete.

Light weight aggregates may be grouped in the following categories:

(i) Naturally occurring materials which require further processing such as expanded clay, shale and slate, etc.
(ii) Industrial by-products such as sintered pulverized fuel ash (fly ash), foamed or expanded-blast-furnace slag.
(iii) Naturally occurring materials such as pumice, foamed lava, volcanic tuff and porous limestone.

Aggregate manufactured from natural raw material

The artificial light weight aggregates are mainly made from clay, shale, slate or pulverized fuel ash, subject to a process of either expansion (bloating) or agglomeration. During the process of expansion the material is heated to fusion temperature at which point pyroplasticity of material occurs simultaneously with the formation of gas. Agglomeration on the other hand occurs when some of the material fuses (melts) and various particles are bonded together.

i. Expanded or bloated clay

- Made from a special; grade of clay suitable for expansion.
- The ground clay mixed with additives which encourages bloating, is passed through a rotary or vertical shaft kiln fired by a mixture of pulverized coal and oil with temperature reaching about 1200^0C.
- The material produced consists of hard rounded particles with a smooth dense surface texture and honeycomb interior.

ii. Expanded shale

- Crushed raw material such as colliery waste, blended with ground coal is passed over a sinter strand reaching a temperature of about, 1200^0C.
- At this temperature the particles expand and fuse together trapping gas and air within the structure of the material with a porous surface texture.

iii. Expanded slate

- Crushed raw material is fed into a rotary kiln with temperature reaching 1200^0C.
- Material produced is chemically inert and has a highly vitrified internal pore structure.
- This material is then crushed and graded.

iv. Exfoliated vermiculite

- The raw material resembles mica in appearance and consists of thin flat flakes containing microscopic particles of water.
- On being suddenly heated to a high temperature of about 700-1000^{0}C, the flakes expand (exfoliate) due to steam forcing the laminates apart.
- The material produced consists of accordion granules containing many minute air layers.

Industrial by-product light weight aggregate

i. Sintered pulverized fuel ash

- The fly ash collected from modern power stations burning pulverized fuel, is mixed with water and coal slurry in screw mixers and then fed onto rotating pans, known as pelletizers, to form spherical pellets.
- The green pellets are then fed onto a sinter strand reaching a temperature of 1400^{0}C.
- At this temperature the fly ash particles coagulate to form hard brick like spherical particles.
- The produced material is screened and graded.

ii. Foamed or expanded-blast-furnace slag

- It is a by-product of iron production formed by introducing water or steam into molten material.
- The material produced after annealing and cooling is angular in shape with a rough and irregular glassy texture, and an internal round void system.

Naturally occurring light weight aggregates

The common examples are pumice and diatomite. Pumice is light and strong enough to be used in its natural state, but has variable qualities depending upon its source. It is chemically inert and usually has a relatively high silica content of approximately 75 per cent. Diatomite is a semiconsolidated sedimentary deposit formed in cold water environment.

In India, raw light weight aggregates are produced by using any of the following:

i. Bloated clay aggregates by bloating suitable clays with or without additives
ii. Sintered-fly-ash aggregates by sintering the fly ash and
iii. Light weight aggregate from blast-furnace slag.

Properties of light weight aggregates

The aggregate make up approximately 75% of the total volume of concrete, it influences the workability, strength, modulus of elasticity, density, durability, thermal conductivity, shrinkage and creep. A light weight aggregate concrete should possess low thermal conductivity.

i. Low density

- The density of concrete varies from 300 to 1200 kg/m^3.
- The lightest grade is suited for insulation purposes while the heavier grades with adequate strength are suited for structural applications.
- The low density of cellular concrete makes it suitable for precast floor and roofing units which are easy to handle and transport from the factory to the sites.

ii. High strength

- Cellular concrete has high compressive strength in relation to its density.
- The tensile strength of aerated cellular concrete is about 15 to 20 per cent of its compressive strength.
- Due to a much higher strength to mass ratio, the cellular concrete floor and roof slabs are approximately of one quarter of the weight of normal reinforced concrete slabs.

iii. Thermal insulation

- The insulation value of light weight concrete is about three to six times that of bricks and about ten times that of concrete.
- A 200 mm thick wall of aerated concrete of density 800 kg/m^3 has the same degree of insulation as a 400 mm thick brick wall of density 1600 kg/m^3.

iv. Fire resistance

- Light weight concrete has excellent fire resisting properties.
- Its low thermal conductivity makes it suitable for protecting other structures from the effects of fire.

v. Shrinkage

- Light weight concrete is subjected to shrinkage but to a limited extent.
- The autoclaving of cellular concrete reduces drying shrinkage to one fifth of that occurring during air-curing.

vi. Repairability

- Light weight products can be easily sawn, cut, drilled or nailed. This makes the construction easier.
- Local repairs to the structure can also be attended to as and when require without affecting the rest of the structure.

vii. Durability

- Aerated concrete is only slightly alkaline. Due to its porosity and low alkalinity it does not give rust protection to steel which is provided by dense compacted concrete. The reinforcement used, therefore, requires special treatment for protection against corrosion.

viii. Speed of construction

- With the adoption of prefabrication, it is possible to design the structure on the concept of modular coordination which ensures a faster rate of construction.

ix. Economy

- Due to light weight and high strength to mass ratio of cellular concrete products, their use results in lesser consumption of steel
- A saving of as much as 15 to 20 percent in the cost of construction of floors and roofs may be achieved by using this type of construction compared to conventional construction.

x. Quality control

- A better quality control is exercised in the construction of structure with light weight concrete products owing to the use of factory made units.

Applications

i. As load bearing masonry walls using cellular concrete blocks.
ii. As precast floor and roof panels in all types of buildings.
iii. As a filler wall in the form of precast reinforced wall panels in multi-storeyed buildings.
iv. As partition walls in residential, institutional and industrial buildings.
v. As in-situ composite roof and floor slabs with reinforced concrete grid beams.
vi. As precast composite wall or floor panels.
vii. As insulation cladding to exterior walls of all types of buildings, particularly in office and industrial buildings.

FOAMED CONCRETE (AERATED CONCRETE)

- It is made by introducing air or gas in to a slurry composed of Portland cement or lime and crushed siliceous filler so that when the mix set and hardens, a uniformly cellular structure is formed or in to the plastic mix of mortar in order to produce a material with a cellular structure, containing voids between oil and 1mm in size.

- It is also known as **gas concrete or cellular concrete**

Manufacture of Aerated concrete:-

Manufacture of Aerated concrete by the following ways:

(a) By the formation of gas by chemical reaction within the mass during liquid or plastic state

- Powdered Zinc or aluminium powder is used for the generation of gas or air in the concrete
- The mortar must be of the correct consistence so that the gas can expand the mortar but does not escape
- The reaction of active aluminium powder which we added with the calcium peroxide or with the alkalies liberates hydrogen bubbles.

(b) In the second method of manufacture of aerated concrete, stable foam is mixed with cement and crushed sand slurry thus causing the cellular structure when this gets set and hardened.

(c) By using finely powdered metal (usually aluminium powder) with the slurry and made to react with the calcium hydroxide liberated during the hydration process to give out large quantity of hydrogen gas. This hydrogen gas when contained in the slurry mix gives the cellular structure.

Gasification is the most widely adopted method for the manufacture of foamed concrete. This method is adopted in the large scale manufacture of aerated concrete in the factory where the whole process is mechanized and the product is subjected to high pressure steam curing.

Properties of Foamed concrete

1) Low density. The aerated concrete is made in the density range from 300 kg/m^3 to about 800 kg/m^3. Lower density grades are used for insulation purpose. While the medium density grades are used for the manufacture of building blocks or the load bearing walls and comparatively higher density grades are used in the manufacture of pre-fabricated structural members in conjunction with steel reinforcement.

2) Low thermal conductivity

3) Good resistance to froast action

4) High water absorption

NO FINE CONCRETE

- This concrete is obtained by omitting fine aggregate from the mix
- This type of no fine concrete is made up of only coarse aggregate, cement and water
- Aggregates used for no-fine concrete are normally of size passing through 20 mm and retained on 10 mm

Properties:-

- Low density
- Bond strength of no-fine concrete is very low
- Low drying shrinkage
- Simple rodding is sufficient for full compaction of no fine concrete.

Application/uses of no-fine concrete

1) Used in large scale for external walls for single storey and multi storied buildings

2) Due to high thermal insulating property, it can be used for external walls for heat insulation

3) Because of rough texture, it gives a good base for plastering

4) Where sand is not available, no fine concrete should become a popular construction material

HIGH STRENGTH CONCRETE

Concrete is generally classified as Normal Strength Concrete (NSC), High Strength Concrete (HSC) and Ultra High Strength Concrete (UHSC). There are no clear cut boundary for the above classification. Indian Standard Recommended Methods of Mix Design denotes the boundary at 35 MPa between NSC and HSC. They did not talk about UHSC. But elsewhere in the international forum, about thirty years ago, the high strength lable was applied to concrete having strength above 40 MPa. More recently, the threshold rose to 50 to 60 MPa. In the world scenario, however, in the last 15 years, concrete of very high strength entered the field of construction, in particular construction of high-rise buildings and long span bridges. Concrete strengths of 90 to 120 MPa are occasionally used.

Strength Classification of Concrete

	Conventional Concrete	High-strength Concrete	Very-high-Strength Concrete	Ultra-high-Strength Concrete
Strength (MPa)	< 50	50-100	100-200	>200
w/c ratio	0.45-0.55	0.45-0.30	0.30-0.24	< 0.24
Chemical admixtures	Not necessary	WRA/HRWRA necessary	HRWRA essential	HRWRA essential
Mineral admixtures	Not necessary	Fly ash/slag/ metakaolin /rice husk ash	Silica fume	Silica fume & fly ash
Permeability coefficient (cm/s)	10^{-10}	10^{-11}	10^{-12}	$< 10^{-14}$
Air entrainment	necessary	necessary	necessary	Not necessary

In the modern batching plants high strength concrete is produced in a mechanical manner. Of course, one has to take care about mix proportioning, shape of aggregates, use of supplementary cementitious materials, silica fume and superplasticizers. With the modern equipments, understanding of the role of the constituent materials, production of high strength concrete has become a routine matter.

There are special methods of making high strength concrete. They are given below.

(a) Seeding
(b) Re-vibration
(c) High speed slurry mixing;
(d) Use of admixtures
(e) Inhibition of cracks
(f) Sulphur impregnation;
(g) Use of cementitious aggregates.

Seeding:

This involves adding a small percentage of finely ground, fully hydrated Portland cement to the fresh concrete mix. The mechanism by which this is supposed to aid strength development is difficult to explain. This method may not hold much promise.

Re-vibration:

Concrete undergoes plastic shrinkage. Mixing water creates continuous capillary channels, bleeding, and water accumulates at some selected places. All these reduce the strength of concrete. Controlled re-vibration removes all these defects and increases the strength of concrete.

High Speed slurry mixing:

This process involves the advance preparation of cement water mixture which is then blended with aggregate to produce concrete. Higher compressive strength obtained is attributed to more efficient hydration of cement particles and water achieved in the vigorous blending of cement paste.

Use of Admixtures:

Use of water reducing agents are known to produce increased compressive strengths.

Inhibition of cracks:

Concrete fails by the formation and propagation of cracks. If the propagation of cracks is inhibited, the strength will be higher. Replacement of 2– 3% of fine aggregate by polythene or polystyrene "lenticules" 0.025 mm thick and 3 to 4 mm in diameter results in higher strength. They appear to act as crack arresters without necessitating extra water for workability. Concrete cubes made in this way have yielded strength upto 105 MPa.

Sulphur Impregnation:

Satisfactory high strength concrete have been produced by impregnating low strength porous concrete by sulphur. The process consists of moist curing the fresh concrete specimens for 24 hours, drying them at 120°C for 24 hours, immersing the specimen in molten sulphur under vacuum for 2 hours and then releasing the vacuum and soaking them for an additional ½ hour for further infiltration of sulphur. The sulphur-infiltrated concrete has given strength upto 58 MPa.

Use of Cementitious aggregates:

It has been found that use of cementitious aggregates has yielded high strength. Cement fondu is kind of clinker. This glassy clinker when finely ground results in a kind of cement. When coarsely crushed, it makes a kind of aggregate known as ALAG. Using ALAG as aggregate, strength upto 125 MPa has been obtained with water/cement ratio 0.32.

Advantages of Using HSC

- Reduction in member size, resulting in an increase in the usable floor space, a reduction in the quantity of concrete and a consequent reduction in construction time.
- Reduction in self weight and a consequent reduction in the foundation cost.
- Reduction in the area of formwork and the time required for stripping forms.
- The ability to withstand large column loads with reasonable sizes of column
- Provision of large span or elimination of a few columns or smaller beams for comparable spans, leading to a reduction in the storey height from headroom considerations
- Reduction in axial shortening effects in columns
- Reduction in floor thickness and beam height
- Superior durability and long term performance
- Lower creep and shrinkage
- Larger stiffness as a result of a larger value of Young's modulus of concrete
- Higher resistance to crack propagation, chemical attack etc
- Reduced maintenance cost

ULTRA HIGH STRENGTH CONCRETE

As technology advances, it is but natural that concrete technologists are directing their attention beyond high strength concrete to ultra-high strength concrete. The following techniques are used for producing ultra-high strength concrete.

(a) Compaction by pressure

(b) Helical binding;

(c) Polymerization in concrete

(d) Reactive powder concrete.

Compaction by Pressure:

It has been pointed out earlier that cement paste derives strength due to the combined effect of friction and bond. In ceramic material, grain size and porosity would be the most important parameters affecting friction and bond and hence the strength. It has been attempted to reduce grain size and porosity by the application of tremendous pressure at room temperature and also at higher temperature.

Helical Binding:

This is an indirect method of achieving ultra-high strength in concrete. High tensile steel wire binding externally over the concrete cylinder results in good strength.

Polymer Concrete:

Impregnation of monomer into the pores of hardened concrete and then getting it polymerized by irradiation or thermal catalytic process, results in the development of very high strength. This method of making ultra-high strength concrete holds much promise. This aspect has been discussed in detail in Chapter 12 under special concrete.

Reactive Powder Concrete:

Reactive powder concrete (RPC) is the ultra-high strength concrete prepared by replacing the ordinary aggregate of normal concrete with quartz powder, silica fume, steel fibers etc. RPC not only has high strength but also has high ductility. Its compressive strength ranges from 200 Mpa to 800 Mpa.

ROLLER COMPACTED CONCRETE

Roller Compacted concrete (RCC) is a mixture of aggregates, cement with or without supplementary cementing materials, water and in some cases water reducing admixture, proportioned to support external compaction equipment. This is a stiff (dry and lean), zero slump concrete mixture.

The low water content requires it to be *mixed in a continuous flow system, spread with a modified asphalt paver* and *compacted with a roller.* The resulting product is a construction material with the strength and characteristics of conventional concrete.

In comparison to conventional concrete, RCC requires only 60 to 75 percent cement and avoids the undesirable conditions created by the high heat of hydration in mass concrete. Water content is low that the freshly mixed RCC looks like damp gravel. It is transported in dump trucks or pavers or loaders to the construction site and spread with bulldozers or conventional asphalt spreaders in 200-300mm thick layers called *Lifts.* Lifts are then compacted using vibratory steel-wheel and pneumatic tire rollers. Immediately after the completion of compaction water is sprayed as fine mist to cure the concrete.

A major concern in roller concrete design is to obtain an adequate bond between the lifts.

Construction Process

For effective consolidation, concrete mixture must be dry enough to support the weight of the vibratory equipment but wet enough to permit adequate distribution of paste binder.

The construction process for RCC is a three-step cycle that results in continuous placement of mix to eliminate the delay in laying the subsequent lifts. The three steps are

(a) Mix Proportioning
(b) Transportation to site, and
(c) Spreading compaction and curing

Following are the factors affecting *mix proportioning of RCC*

Cement: The cement and cementing material content in RCC normally varies approximately between 12 and 15 percent of dry materials, i.e. from 250 to 350 kg/m^3 in the wearing course and in the base course it varies from 100 – 150 kg/m^3

Pozzolana: Modern RCC is in fact fly ash modified lean concrete containing high volume fly ash and very low water content. Use of fly ash in RCC mixtures helps to increase paste content, improves Compactability, results in low heat of hydration, low shrinkage and delay in initial and final setting times. Fly ash improves long term strength and durability of concrete

Aggregate: The aggregate comprises approximately 75 to 85 percent of the volume of RCC and hence affects significantly both fresh and hardened concrete. The use of continuously graded aggregates is desirable for best results.

Admixture: Air entraining, water reducing and set controlling admixtures are effective in reducing the vibration time required for full consolidation of the RCC.

After mixing, RCC is transported to the site, and is placed and compacted in lifts in final position, with vibratory rollers to maximum density. Finishing compaction is done by pneumatic tire roller. After the compaction, the paved surface is covered by curing mat and covered with water spray.

Advantages of RCC

- Reduction in quantity of cement
- Reduced manual work
- Elimination of formwork
- Speed of construction leads to cost savings
- Exhibits lower shrinkage
- Creep is considerably less

Applications

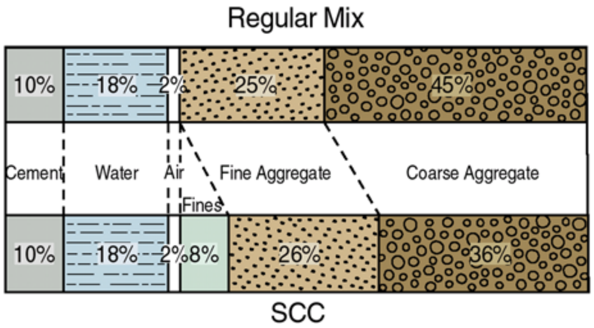
RCC has established itself as a fast economical construction methods for

- Dams
- Highway pavement (RCC pavement)
- Roads in factories
- Temporary roads for construction works
- Material handling yards
- Carriageway of airports

SELF COMPACTING CONCRETE

Definition and Significance

- SCC or super-workable concrete or self-consolidating concrete is a highly flowable or self-leveling, cohesive concrete that can spread through and around dense reinforcement under its own weight
- It adequately fills voids without segregation or bleeding
- Self-compacting concrete (SCC) does not require compaction through vibrators while placing
- Useful in situations where vibration is difficult and reinforcing steel is highly congested
- Originally developed in Japan in 1980 to offset a growing shortage of skilled labour
- The technology of SCC is based on increasing the fine material like fly ash, limestone filler etc. without changing the water content compared to conventional concrete



Material for SCC

- Materials used the same as used in the conventional concrete
- However to transform the conventional concrete into a SCC, aggregate shape, size, grading, cement and water contents and admixture dosage have to be carefully selected and proportioned

Cement – OPC 43 or 53 grade can be used

Coarse aggregate – well graded cubical or rounded are desirable as they minimize the paste content as well as admixture dosage
– Maximum size of aggregate is limited to 20 mm
– Aggregate of 10 to 12 mm is desirable for structures having congested reinforcement

Fine aggregate – Can be natural or manufactured and should be of uniform grading
– To achieve a balance between fluidity and stability, total fine content is high

Chemical admixtures – Superplasticizer is an essential component of SCC to provide necessary workability
– Viscosity modifying agents (VMA) for stability
– Air entraining agents (AEA) to improve the freeze-thaw resistance
– Retarders for controlling setting

Mineral admixtures – Fly ash in appropriate quantity added to improve the quality and durability of SCC
– Silica fume added to improve the mechanical properties
– Stone powder may be used to increase the fine content
– Fibers used to enhance the properties of SCC

Types of SCC

Three ways in which SCC can be made

1. *Powder type SCC*
   - Is made by increasing the powder content
   - Mix achieves the fluidity requirements through the use of large amount of fine aggregates and a High Range Water Reducer (HRWR)
2. *VMA type SCC*
   - Fines content is same as that of conventional concrete
   - Required viscosity to inhibit segregation is ensured by using a Viscosity Modifying Admixture (VMA)
3. *Combination type*
   - Made by increasing powder content and VMA

Requirements for self-compacting concrete

The main characteristics of SCC are the properties in the fresh state. The mix design is focused on the ability to flow under its own weight without vibration, the ability to flow through heavily congested reinforcement under its own weight, and the ability to retain homogeneity without segregation.

A concrete mix can only be classified as self-complicating if it has the following characteristics.

- *Filling ability* : The ability to flow into and completely fill complex forms under its own weight
- *Passing ability* : The ability to pass through and bond to dense reinforcement under its own weight
- *Segregation resistance* : This represents high stability for SCC by high resistance to aggregate segregation

Test Methods for SCC

1. *Slump Flow Test*

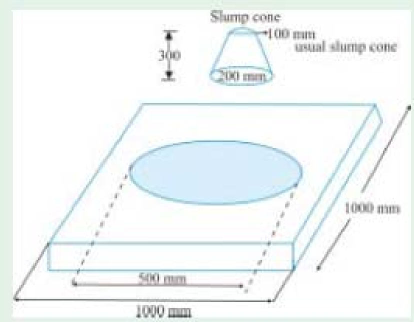


Fig. 12.24. Slump flow test

- To assess the horizontal flow of concrete in the absence of obstructions
- Most commonly used test and gives good assessment of filling ability
- Also indicates the resistance to segregation
- *Equipment:*
  - # Usual slump cone
  - # A stiff base plate square in shape
- *Procedure:*
  - # Place base plate on a level ground and keep the slump cone centrally on the base plate
  - # Fill the cone with concrete
  - # Raise the cone vertically and allow the concrete to flow freely
  - # Measure the final diameter of the concrete in two perpendicular directions and calculate the average of the two diameters
- *Interpretation*
  - # The higher the flow value, the greater its ability o fill formwork under its own weight
  - # A value of at least 650 mm is required for SCC

2. *V-Funnel Test*

- Used to determine the filling ability of concrete with a maximum size of aggregate 20 mm
- The equipment consists of a v-shaped funnel
- The funnel is filled with about 12 liters of concrete
- Find the time taken for it to flow down

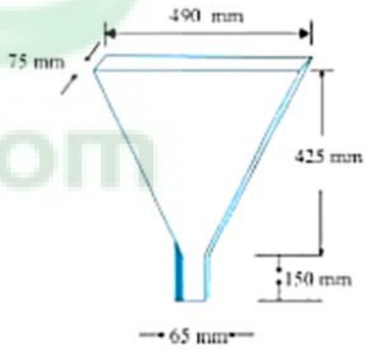
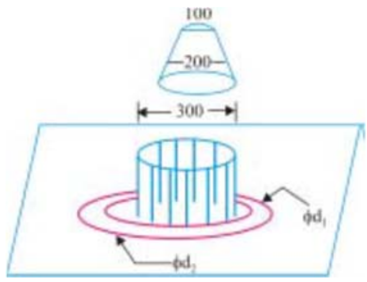


Fig. 12.26. V-Funnel Test Equipment

3. *J-Ring Test*

- Denotes the passing ability of concrete
- Equipment consists of an open steel ring drilled vertically with holes to accept reinforcing bars of 10 mm diameter 100 mm in length
- Bars can be placed at different distances apart to simulate the congestion of reinforcement
- Slump cone & Base plate are other equipment



- *Procedure:*
  - # Moisten the inside of the slump cone and base plate
  - # Place the J-ring on the base plate and the slump cone centrally inside the J-ring
  - # Fill the slump cone
  - # Raise the concrete vertically and allow the concrete to flow out through the J-ring
  - # Measure the final diameter in two perpendicular directions and calculate the average
  - # Measure the difference in height between the concrete just inside the J-ring bars and just outside the J-ring bars

Structural Properties of SCC

The compressive strength and tensile strengths, modulus of elasticity and durability of well-designed SCC are in the same order of magnitude as the conventional vibrated concrete.

Production and Placing of SCC

Aggregates: Aggregate should come from same source. There should not be much variations in size, shape and moisture content.

Mixing: Any suitable mixer could be used - Generally, mixing time need to be longer than for conventional concrete. Time of addition of admixture is important. A system should be established for optimum benefit during trial itself.

In the beginning there may be fluctuations in the quality of freshly mixed concrete. It is recommended that every batch must be tested until consistent and compliant results are obtained.

Subsequently, checking could be done “by the eye” and routine testing is sufficient.

Placing: Formwork must be in good conditions to prevent leakage. Though it is easier to place SCC than ordinary concrete, the following rules are to be followed to minimize the risk of segregation.

- Limit of vertical free fall distance to 5 meter.
- Limit the height of pour lifts (layers) to 500 mm
- Limit of permissible distance of horizontal flow from point of discharge to 10 meters.

Curing: On account of no bleeding or very little bleeding, SCC tends to dry faster and may cause more plastic shrinkage cracking. Therefore, initial curing should be commenced as soon as practicable. Alternatively the SCC must be effectively covered by polyethylene sheet. Due to the high content of powder, SCC can show more plastic shrinkage or creep than ordinary concrete mixes. There are disagreements on the above statement. These aspects should be considered during designing and specifying SCC. It should also be noted that early curing is necessary for SCC.

Advantages of SCC

- Easier and rapid placement in members with dense reinforcement and complicated formwork results in faster construction and reduction in cost of production
- Reduction on site manpower
- Relatively low w/c ratio results in rapid strength development, improved quality, strength and durability
- Produces good surface finish particularly for slabs
- Reduce noise levels due to absence of vibration
- Safer and cleaner working environment

Disadvantages of SCC

- Increased formwork pressure requires slower casting rate
- SCC with low w/c ratio results in rapid drying and thus requires increased curing to avoid shrinkage cracking
- SCC is more prone to settlement cracks
- Though most of common concrete mixers can be used for producing SCC, mixing time is longer

READY MIXED CONCRETE

- Ready mixed concrete (RMC) is a concrete whose constituents are batched at a central batching plant
    - Mixed either at the plant or en route in truck mixers
    - Transported to the site
    - Delivered in a condition ready to use
- Useful in congested sites
- Produced under factory conditions: Permits a close control of all operations of manufacture and transportation of fresh concrete
- One of the most versatile and popular building material: Durability, low cost and ability to be customized for various applications
- Quantity and quality required is specified by the customer

Advantages of RMC

- Superior quality
- Reduced the wastages of material
- Eliminate the problem of storage of material
- Reduce supervision & labour cost
- Safe & hygienic condition
- Fluctuation of raw material cost & non-availability of material eliminate
- Reduces the problem of inspection, checking & testing
- Roads & footpath are not blocked
- Improve the environment

Placing Order for RMC

- RMC is ordered and supplied by volume (cubic metre) in a freshly mixed and unhardened state
- Can be ordered in several ways

  (i) *Recipe batch*
    - Purchaser assumes responsibility for proportioning the concrete mixture
    - Specify the cement content, maximum allowable water content, admixtures required and amount and type of coarse aggregate
    - Producer assumes full responsibility for the resulting strength and durability of the mixture

  (ii) *Performance batch*
    - Purchaser specifies the requirements for the strength of the concrete, and manufacturer assumes full responsibility for the proportions of various ingredients that go into the batch

  (iii) *Part performance and part recipe*
    - Purchaser specifies a minimum cement content, the required admixtures and the strength requirements
    - Manufacturer proportion the concrete mixture within the constraints imposed

Proportioning of RMC

- RMC embodies the concept of treating concrete as building material rather than ingredients
- Proportioning of RMC aims at obtaining an economical and practical combination of materials to produce a concrete with desired properties (workability, strength, durability and appearance)

- Aggregates are required to meet appropriate specifications (In general should be clean, strong and durable)
- Fly ash or other supplementary cementing materials, which enhance the concrete properties, are normally added to RMC
- Key to quality of concrete is to use the least amount of water that can result in a mixture which can be easily placed, compacted and finished
- Admixtures are used in relative small quantities to improve the properties of fresh and hardened concrete
  - # Air-entraining agent imparts durability to concrete in freezing and thawing exposure
  - # Water reducing admixtures increase the strength and improve durability
  - # Fibers are incorporated in concrete to control the cracking and improve abrasion and impact resistance

Production of RMC

Storage of Constituent materials

- Aggregates
  - # Properly stored to avoid cross-contamination between different types and sizes
  - # Protected from weather
  - # Sufficient quantity should be stored in advance
- Cement, Additives and Admixtures
  - # Recommendations of the manufacturer for storage shall always be followed
  - # Should be collected and stored in advance

Mixing equipment and trial mixes

- Can be produced using any efficient concrete mixers such as paddle mixers, free-fall mixers and truck mixers, but forced action mixers are preferred
- Preliminary trials needs to be carried out to ascertain the efficiency of mixers and optimum sequence for addition of constituents
- Readymade self-compacting concrete may take longer time to achieve complete mixing than for normal concrete to fully activate the super plasticizer

Plant-mixing procedures

- Mixing should be such that result in a uniform mix without any balling
- Admixtures should not be added directly to dry constituents but dispensed together with or in the mixing water
- Different types of admixtures should not be blended together prior to dispensing unless specifically approved by the admixture manufacturer
- If air entraining admixtures are used, they are best added before the super plasticizer and when concrete is at a lower consistency

Methods to load the mixer

- Free-fall mixers
  - # In the first instance approximately two-thirds of the mixing water is added to the mixer and is followed by aggregates and cement
  - # When a uniform mix is obtained, the remaining mixing water and the super plasticizer are added
  - # Truck mixers require additional mixing time for RMC as they are less efficient than plant mixers
- Forced action mixers
  - # Aggregate is added to the mixer first along with the cement
  - # Followed by main mixing water and super plasticizer
  - # When admixtures are used, it is added with the final water

Classification of RMC

Transit-mixed or truck mixed concrete

- Materials batched at a central plant and mixed during the period of transit to the site or immediately prior to concrete being discharged
- All the raw ingredients are charged directly into the truck mixer
- Water is usually batched at the central plant
- The mixer drum is turned at charging (fast) speed during the loading of materials
- Three options for truck mixed concrete
  - # Concrete mixed at the job site
  - # Concrete mixed at the yard or central batching plant
  - # Concrete mixed in transit

Shrink mixed concrete

- Concrete is partially mixed in a central plant
- Discharged into the drum of a truck mixer for completion of the mixing
- Two minutes of mixing in truck drum at mixing speed is sufficient to completely mix the concrete

Central mixed concrete

- Concrete is mixed in the central plant and is discharged into the truck mixer
- Truck mixer is used as agitating haul unit
- Advantages
  - # Faster production capability
  - # Improved concrete quality control and consistency
  - # Reduced wear on truck mixer drums

Discharging RMC

RMC can be placed

- By pump (Most common method)
- Placing by chute or skip
  - # Direct discharge from truck through a chute
  - # Discharged into a skip

FIBRE REINFORCED CONCRETE

Introduction

- Concrete is relatively brittle, and its tensile strength is typically only about one tenths of its compressive strength. Regular concrete is therefore normally reinforced with steel reinforcing bars.
- For many applications, it is becoming increasingly popular to reinforce the concrete with small, randomly distributed fibers. Their main purpose is to increase the energy absorption capacity and toughness of the material, but also increase tensile and flexural strength of concrete.
- *Concrete containing a hydraulic cement, water, fine or fine and coarse aggregate and discontinuous discrete fibers is called fiber-reinforced concrete (FRC).* Fibers of various shapes and sizes produced from steel, plastic, glass, and natural materials are being used; however, for most structural and nonstructural purposes, *steel fiber is the most commonly used of all the fibers*.
- There is considerable improvement in the post-cracking behavior of concretes containing fibers. Compared to plain concrete, fiber reinforced concrete is much tougher and more resistant to impact.

Areas of Application of FRC materials

- Thin sheets
- Shingles
- roof tiles
- pipes

- prefabricated shapes
- panels
- shotcrete
- curtain walls
- Slabs on grade
- precast elements
- Composite decks
- Vaults, safes.
- Impact resisting structures

Different types of fibres

Steel fibres and glass fibres are generally suited for structural application using cement concrete, since they possess high modulus of elasticity and consequently lead to strong and stiff composites.

Type of Steel Fibre	Tensile Strength (Mpa)	Young's Modulus (10^3 Mpa)	Ultimate Elongations (%)	Specific Gravity
Steel	275-2758	200	0.5-35	7.86
Glass	1034-3792	69	1.5-3.5	2.5
Asbestos	551-965	89-138	0.6	3.2
Rayon	413-620	6.89	10-25	1.5
Cotton	413-689	4.82	3-10	1.5
Nylon	758-827	4.13	16-20	1.1
Polypropylene	551-758	3.45	25	0.90
Acrylic	206-413	2.06	25-45	1.1

Aspect ratio

Aspect ratio of the fibre is the **ratio of its length to its diameter**. Typical aspect ratio ranges from 30-150. The steel fibre content in a structural component is generally of the order of 1% to 4% by volume and aspect ratio is kept between 70 to 100 for most of the structural application.

Effect of aspect ratio on strength and toughness of material is as under

Types of concrete	Aspect Ratio	Relative Strength	Relative Toughness
Plain concrete with Randomly distributed Steel fibre	0 25	1.00 1.50	1.0 2.0
Dispersed fibre	50 75 100	1.60 1.70 1.50	8.00 10.50 8.50

Compression

Experimental studies indicate that except in the case of steel fibres, adding fibres to a concrete matrix does not improve compressive strength. The compressive strength improvement with steel fibres ranged from 0 to 15%.

However, the presence of any type of fibre matrix changes the basic stress strain characteristics while the ascending portion of the curve is slightly modified. A higher fibre content produces less steep descending portion, which results in high ductility and toughness of materials.

Orientation of fibres

In conventional reinforcement, steel bars are oriented in the direction desired, while in fibre reinforced concrete, fibres are randomly oriented. But it is proved from the test that the *parallel orientation gives more strength*. It was observed that the fibres aligned parallel to the applied load offered more tensile strength and toughness than randomly distributed or perpendicular fibres.

Direct tension

Reliable and valid direct tensile testing of concreting and Fibre Reinforced Concrete (F.R.C) is very difficult to carry out because of the brittle nature of concrete. Indirect methods of measuring stress strain, using curves have also been attempted. It has observed that Steel Fibre Reinforced Concrete (S.F.R.C) has superior tensile properties, particularly ductility, over plain concrete.

Ductility

The ductility of material contributes to the ability of the structure to withstand imposed deformation and the effects of normal and abnormal loads without unacceptable damage. Nowadays the significance of ductility of concrete is gaining due recognition. Sufficient ductility can be induced by the use of steel fibres in cement concrete.

Increase in ductility of S.F.R.C., due to its crack arresting property, imparts a greater energy absorbing capacity to the composite to withstand failure. With 2.5 percent fibre content, the energy absorbing capacity increases by more than 10 times.

The ductility of material contributes largely to the ability of the structure to withstand imposed deformation and the effects of loads without damage. Sufficient ductility can be generated by the use of steel fibres.

Factors affecting properties of FRC

1. *Volume of fibres*
   - Increase in the volume of fibre increases the toughness and tensile strength of concrete
   - Use of higher percentage of fibre is also causes the segregation and harshness of concrete and mortar
2. *Aspect Ratio*
   - Up to aspect ratio of 75, is preferable. Increase in aspect ratio increases the toughness and ultimate strength of concrete linearly
3. *Orientation of fibre*
   - Fibres aligned parallel to the applied load offers more tensile strength and toughness than randomly distributed or perpendicular fibres
4. *Size of coarse aggregate*
   - To avoid appreciable reduction in strength of composite, the maximum size of coarse aggregate should be restricted to 20 mm
5. *Mixing:-*
   - Fibres should be dispersed uniformly throughout the mix. This can be done by the addition of fibres before the water is added.
6. *Workability*
   - Incorporation of steel fibre decreases the workability. The workability and compaction of the mix is improved through increased water/cement ratio, or use of water reducing admixtures.

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Mix Proportion of FRC

The typical proportions of fibre reinforced concrete

Cement content	325-550 kg/m^3
W/C ratio	0.4 to 0.6
Percentage of sand to total aggregate	50 to 100 %
Maximum aggregate size	10 mm
Air-content	6 to 9 %
Fibre-content	0.5 to 0.25 % by volume of mix Steel – 1 percent 78 kg/m^3 Glass – 1 percent 25 kg/m^3 Nylon – 1 percent 11 kg/m^3

Steel Fibre Reinforced Concrete (SFRC)

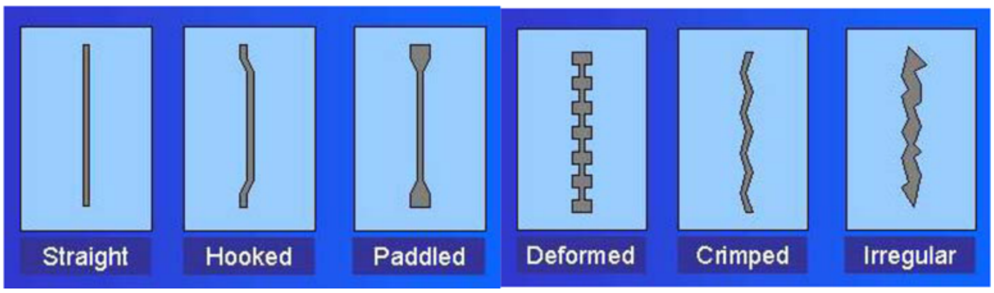
- SFRC is a composite material made of hydraulic cements, water, fine and coarse aggregate, and a dispersion of discontinuous, small fibers. It may also contain pozzolans and admixtures commonly used with conventional concrete.
- Steel fibers are distributed uniformly throughout the concrete matrix.
- The primary function of steel fibers is to *modify micro and macro cracking*. By intercepting cracks at their origin, the steel fibers inhibit crack growth. For this reason, SFRC can be used to replace welded wire reinforcement or rebar which is used to control temperature or shrinkage cracks.
- Steel fibers can be introduced into the concrete at the batch plant or jobsite.

Behaviour of steel fibre reinforced concrete:

The addition of steel fibres to cement mortar or concrete leads to improvement in following properties besides improving cracking and tensile strength of the matrix.

- Shear strength
- Fatigue strength
- Torsional strength
- Spalling resistance
- Energy absorption
- Resistance to wear
- Resistance freeze and thaw damage
- Resistance to shock and dynamic loading
- Friction and skid resistance
- Impact and fatigue strength
- Fire resistance
- Durability

Types of Steel Fibers



Applications of Steel Fibre Reinforced Concrete (S.F.R.C)

The present applications of S.F.R.C are in the following areas:

- Refractories
- Pavement and overlays
- Manhole covers
- Patching and repair works
- Thin precast roofing & flooring elements
- Mine and tunnel supports and linings
- Pipes, poles
- Industrial flooring
- Caissons
- Machine foundations and structures resisting high impact load
- Rock slope stabilization
- Wall panels
- Bridge decking
- Rapid dome construction
- Car parks
- Blast resistant structures
- Repairs of dam and bridges
- Earthquake resistant structures
- Lining of the steep incline of canals
- Beam-column joint

Glass fibre reinforced concrete (GFRC)

– GFRC was first created in the 1940s in Russia, but it wasn't until the 1970's that the current form came into widespread use.

– Just like regular concrete, GFRC can accommodate a variety of artistic embellishments including acid staining, dying, integral pigmentation, decorative aggregates, veining and more. It can also be etched, polished, sandblasted and stenciled. If you can imagine it, you can do it, making GFRC a great option for creating concrete countertops and especially three-dimensional concrete elements.

– It's made by combining a mixture of fine sand, cement, polymer (usually an acrylic polymer), water, other admixtures and alkali-resistant (AR) glass fibers.

– It can be effectively used to create façade wall panels, fireplace surrounds, vanity tops and concrete countertops due to its unique properties and tensile strength.

– Some of the many benefits of GFRC include:

  - **Ability to Construct Lightweight Panels**- Although the relative density is similar to concrete, GFRC panels can be much thinner than traditional concrete panels, making them lighter.
  - **High Compressive, Flexural and Tensile Strength**- The high dose of glass fibers leads to high tensile strength while the high polymer content makes the concrete flexible and resistant to cracking. Proper reinforcing using scrim will further increase the strength of objects and is critical in projects where visible cracks are not tolerable.

Advantages of Glass Fiber Reinforced Concrete

- Relatively light in weight compared to the traditional stones. Its installation is fast and comparatively simple.
- GFRC has the characteristics to be cast into almost any shape.
- GFRC consists of materials that are unlikely to burn. The concrete takes the role of a thermal regulator while exposed to fire and protects the materials from the flame heat.

- GFRC is thin and strong, with weight being 75% to 90% less compared to solid concrete. Less weight facilitates easy and rapid installation, and also decreases the load applied on the structure. The light weight and tough material also minimizes the transportation expenditures, permits flexibility in design, and reduces the impact on environment.
- GFRC is less vulnerable to weather effects and more resistant to freeze thaw than the normal concrete.

POLYMER CONCRETE

Introduction

Polymers are a large class of materials consisting of many small molecules (called monomers) that can be linked together to form long chains, thus they are known as macromolecules.

Polymer concrete is a composite wherein the polymer replaces the cement-water matrix in the cement concrete. It is manufactured in a manner similar to that of cement concrete. Monomers or pre-polymers are added to the graded aggregate and the mixture is thoroughly mixed by hand or machine. The thoroughly mixed polymer concrete material is cast in moulds of wood, steel or aluminium, etc. to the required shape or form. Mould releasing agent can be added for easy demoulding. This is then polymerized either at room temperature or at an elevated temperature. The polymer phase binds the aggregate to give a strong composite. Polymerization can be achieved by any of the following methods.

(i) Thermal-catalytic reaction
(ii) Catalyst-promoter reaction
(iii) Radiation

In the *first method*, only the catalyst is added to the monomer and polymerization is initiated by decomposing the catalyst by the application of elevated temperatures up to 90^0C. Typical catalysts used for different monomer systems include, benzoyl peroxide, methyl-ethyl-ketone peroxide, benzenesulphonic acid, etc.

In the *second method*, a constituent called promoter or accelerator is also added, which decomposes the catalyst or accelerates the reaction, at the ambient temperature itself. Typical promoters include cobalt naphthanate, dimethyl-p-toluidine, ferric chloride etc. some promoters ensure polymerization at the ambient temperature within an hour.

Gamma radiation is applied in the radiation polymerization method.

Depending on the method of polymerization and the other conditions, polymerization takes place within a period ranging from a few minutes to a few hours. Special precautions are to be taken in handling and cleaning because the monomers are highly inflammable. Fire safety precautions are to be observed. A thoroughly dry aggregate system is to be used as the monomers may not polymerize in the presence of moisture. Moreover, the catalyst and promoter should never be added to each other as it will result in an explosion.

The polymer systems which have been successfully used for polymer concrete include methyl-methacrylate, polyester-styrene, epoxy-styrene, styrene and furfuryl acetone. Others are furane, acrylic, polyurethane, urea formaldehyde and phenol formaldehyde, etc.

The design consideration for polymer concrete is:

a. Smaller the *binder (polymer) content* to fill the voids of the aggregate system content greater is the economy.
b. *Workability* for easy mixing and placing of cement concrete without bleeding and segregation.
c. *Film forming ability* of the polymer, and bonding with the aggregate surface to transmit load forces.
d. *Economic curing (cross-linking) times* and temperatures.
e. *Durability* in environments to which the polymer concrete composite is exposed.

Polymer concrete can be reinforced with steel, nylon, polypropylene or glass fibres in a manner similar to cement concrete.

Polymer concretes have good potential as repair material and for overlays. Thin sand-filled overlays (12 to 30 mm thick) reduce water permeability and chloride penetration. Polymer concrete can be used for rapid repair of damaged airfield pavements and industrial structures. Polymer concrete can be used for treating the sluice ways and stilling basin of the dam.

Polymer concrete pipes have been used for transporting a variety of chemicals, for carrying effluents and wastewater, etc.

Polymer concrete can be used in rock bolts. It provides necessary corrosion protection to ground anchors. Polymer concretes possess good electrical properties and can be used for high voltage insulator application. Electrical structures such as poles for electrical transmission lines have been manufactured from polymer concrete.

Advantages of polymer concrete

- Rapid Curing at Ambient temperature
- High Tensile, Flexure & Compressive Strength
- Good Adhesion to most surfaces
- 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
- Light weight
- May be used in regular wood and steel formwork
- May be vibrated to fill voids in forms
- Allows use of regular form-release agents

Types of polymer concrete

1. Polymer Impregnated Concrete (PIC)
2. Polymer Cement Concrete (PCC)
3. Polymer Concrete (PC)
4. Partially Impregnated and surface coated polymer Concrete

1. *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.

– Principal applications include use in structural steel floors, food processing buildings, sewer pipes, storage tanks for sea water, desalination plants and distilled water plants, wall panels, tunnel liners and swimming pools.

– Mainly the following types of monomer are used:
  - Methyl methacrylate (MMA)
  - Styrene
  - Acrylonitrile
  - T-butyl styrene
  - Other thermo plastic monomers

– ***Properties of PIC***

  # PC made with Methyl methacrylate (MMA) is a brittle material that shows a nearly linear stress-strain relationship with high ultimate strength.
  # Compressive strength can be achieved up to 140 Mpa.
  # Tensile and flexural strength increased by 3.9 and 3.6 times respectively.
  # Thermal and creep characteristics of the material are usually not favorable for structural applications of PC.
  # PIC has shown excellent resistance to freeze-thaw resistance

  - # Good results are obtained in sulpahte attack and chemical attack.
  - # A maximum reduction of 95% in water absorption has been observed with concrete containing 5.9% polymer loading.
- **Disadvantages:-**
  - # High cost
  - # Low fire resistant
  - # Low coefficient of thermal expansion
- **Application of PIC:-**
  - # Ferro cement products
  - # Marine works
  - # Nuclear plants
  - # Pre-fabricated structural construction
  - # Sewage disposal works
  - # Water proofing of structures
  - # Industrial applications
    - Chemical factories
    - Dairy farms
    - Ware houses

2. *<u>Polymer Cement Concrete (PCC) or Polymer Modified Concrete (PMC)</u>*

- Polymer-modified concrete is Portland cement concrete with polymer solutions added to the mix to achieve certain properties. Like Portland cement concrete, the primary curing mechanism for polymer-modified concrete is hydration of the cement binder.
- Polymer Cement Concrete is made by mixing cement, aggregates, water and monomer. Such plastic mixture is cast in moulds, cured, dried and polymerized.
- Major applications are in floors, bridge decks, road surfacing and compounds for repair of concrete structures. Latex modified mortar is used for laying bricks, in prefabricated panels and in stone.
- The mixing and handling are similar to Portland cement concrete. However, in the production process, air entrainment occurs without the use of an admixture, and prolonged moist curing is not required.
- The quantities of polymers required for polymer-modified cement concretes are relatively small, being in the range of 1 to 4 per cent by mass of the composite. In contrast polymer impregnated concretes require 5 to 8 per cent and polymer concretes 8 to 15 per cent of polymer. Polymer modified concretes are therefore, the least expensive.
- The monomers that are used in PCC are:
  - Polyster-styrene
  - Epoxy-styrene
  - Furans
  - Vinylidene chloride

3. *<u>Polymer Concrete</u>*

- 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 mould.
- Monomer is then diffused up through the aggregates and polymerization is initiated by radiation or chemical means. A silane 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.

– **Advantages:-**

- High resistance to sulphate attack
- High resistance to abrasion
- High resistance to freezing and thawing

4. *Partially Impregnated and surface coated polymer Concrete*

– Partial impregnation may be sufficient in situations where the major requirement is surface resistance against chemical and mechanical attack in addition to strength increase.

– The partially impregnated concrete could be produced by initially soaking the dried specimens in liquid monomer like methyl methacrylate, then sealing them by keeping them under hot water at 70^0 C to prevent or minimise loss due to evaporation.

– The polymerization can be done by using thermal catalytic method in which three per cent by weight of benzoyl peroxide is added to the monomer as a catalyst.

– The potential application of polymer impregnated concrete surface treatment coated concrete is in improving the durability of concrete bridge decks. Bridge deck deterioration is a serious problem everywhere, particularly due to a abrasive wear, freeze-thaw deterioration, spalling and corrosion of reinforcement.

Sequence of operation

1. *Casting conventional concrete elements:*

– Since the quality of concrete before penetration is not important from the standpoint of properties of the end product, no special care is needed in the selection of materials and proportioning of concrete mixtures.
– Section thickness is generally limited to a maximum of about 150 mm, since it is difficult to fully penetrate thick sections.

2. *Curing the elements:*

– Following the removal of elements from forms, at ambient temperatures conventional moist curing for 28 days or even 7 days is adequate because the ultimate properties of PIC do not depend on the pr penetration concrete quality.
– For fast production schedules, thermal curing techniques may be adopted.

3. *Drying and evacuation:*

– The time and temperature needed for removal of free water from the capillary pores of moist-cured products depend on the thickness of the elements.
– At the drying temperatures ordinarily used (i.e., 105 C), it may require 3 to 7 days before free water has been completely removed from a 150-by 300-mm concrete cylinder.
– Temperatures on the order of 150 C can accelerate the drying process so that it is complete in 1 to 2 days.

4. *Sealing the monomer*

– To prevent loss of monomer by evaporation during handling and polymerization, the impregnated elements must be effectively sealed in steel containers or several layers of aluminum foil;
– in the rehabilitation of bridge decks this has been achieved by covering the surface with sand.

5. *Polymerizing the monomer*

– Thermal-catalytical polymerization is the preferred technique.

SPECIAL PROCESSES AND TECHNOLOGY FOR PARTICULAR TYPES OF STRUCTURE

SHOTCRETE OR GUNITING

Shotcrete is mortar or very fine concrete deposited by jetting it with high velocity (pneumatically projected or sprayed) on to a prepared surface. Shotcerte is frequently more economical than conventional concrete because of less formwork requirements, requiring only a small portable plant for manufacture and placement.

Shotcrete has wide applications in different constructions, such as thin over-head vertical or horizontal surfaces, particularly the curved or folded sections, canal, reservoir and tunnel lining, swimming pools and other water retaining structures and prestressed tanks. It is very useful for the restoration and repair of concrete structures, fine damaged structures and waterproofing of walls.

Types of shotcreting

There are two basic types of shotcreting processes which are described here.

1. Dry mix process
2. Wet mix process

Dry mix process

- Mixture of cement and damp sand is conveyed through a delivery hose pipe to a special mechanical feeder or gun called delivery equipment.
- This material is carried by compressed air to a special nozzle.
- The nozzle is fitted with a perforated manifold through which water is introduced under pressure and intimately mixed with other ingredients.
- The mortar is jetted from the nozzle at high velocity on to the surface to be shotcreted.
- The water-cement ratio should be between 0.33 and 0.50

Wet mix process

- All the ingredients, i.e. cement, sand, small-sized coarse aggregate and water, are mixed before entering the chamber of delivery equipment
- The ready mixed concrete is metered into the feeding chamber and conveyed by compressed air at a pressure of 5.5 to 7 atmospheres to a nozzle.

Procedure

The procedure of shotcreting a surface involves the following steps:

1. *Preparation of surface to receive shotcrete*
   - Where the shotcrete is to be placed against earth surfaces as in canal linings, the surface should first be thoroughly compacted and trimmed to line and grade.
   - It should not be placed on any surface which is frozen, spongy or where there is free water.
   - The surface should be kept damp for several hours before applying shotcreting.
   - For repairing deteriorated concrete it is essential to remove all unsound material.
   - After ensuring that the surface to which the shotcrete is to be bounded is sound, it should be sand-blasted.
   - The nozzleman usually scours clean the area before applying the shotcrete with an air-water jet, and then the water is shut off and all free water is blown away by compressed air.
2. *Construction of forms*
   - The forms are usually of plywood sheeting, true to line and dimension.
   - It should be constructed to permit the escape of air and rebound during the gunning operation.
   - They should also be oiled or dampened.

3. *Placement of reinforcement*

   – The minimum clearance between the reinforcement and the form may vary between 12mm for the case of mortar mix and wire mesh reinforcement to 50mm for the case of concrete and reinforcing bars.

4. *Preparation for succeeding layers*

   – The receiving layer should be allowed to take its initial set before applying a fresh layer of shotcrete.
   – All laitance, loose material and rebound should be removed by brooming.

5. *Finishing of the surface*

   – Natural gun finish is preferred from both structural and durability standpoints.
   – For finer finish, a flash coat consisting of finer sand than normal, and with the nozzle held well back from the surface, is applied to the shotcrete surface as soon as possible after the screeding.

Properties of shotcrete

– In shotcrete, a small-maximum-size aggregate is used and cement content is high. These should enhance durability in most cases.
– The application procedures have a greater effect on the in-place properties of shotcrete than the mix proportions.

UNDER WATER CONCRETING

Placing Concrete under Water

When circumstances demand that concrete be placed under water, every effort should be concentrated on assuring continuity of placement between the construction joints. Puddling or any other type of physical disturbance should be carefully avoided once the concrete is in place, and every possible precaution should be taken to minimize segregation.

Performance Requirements for Underwater Concrete in Structural Applications

– Flowability and Self-Compaction
– Workability Retention within Work Window
– Cohesion Against Washout, Segregation, and Laitance Formation
– Low Bleeding
– Low Heat of Hydration
– Controlled Set Time
– Compressive Strength

Concreting methods

1. Placing in dewatered caissons or coffer dams
2. Tremie method
3. Bucket placing
4. Placing in bags
5. Prepacked concrete

1. Tremie method

This is a method on how to place concrete underwater, this method place a big role in offshore concreting, since cement loses its strength and fade away under water, Tremie method is to be used. Tremie Concrete is done by using a formwork/pipe which will have one end of the formwork/pipe above water and other bottom end immersed under the water and with the help of gravity.

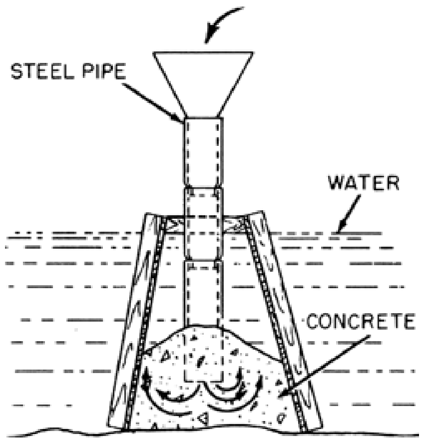
A tremie is a watertight pipe, generally 250mm in diameter, having a funnel shape hopper at its upper end and a loose plug at the bottom or discharge end. The valve at the discharge end is used to de-water the tremie and control the distribution of the concrete. The tremie is supported on a working platform above water level, and to facilitate the placing it is built up in 1 to 3.5m section.

During the concreting, air and water must be exclude from the tremie by keeping the pipe full of concrete all the time; and for this reason the capacity of the hopper should be at least equal to that of the tremie pipe. In charging the tremie a plug formed of paper is first inserted into the pipe as the hopper is filled the pressure of fresh concrete forces the plug down the pipe, and the water in the tremie I displaced by concrete.

For concreting, the tremie pipe is lowered into position and the discharge end is kept as deeply submerged beneath the surface of freshly placed concrete as the placed concrete as the head of concrete in tremie permits. As concreting proceeds the pipe is raised slightly and the concrete flows outwards. Care should be taken to maintain continuity of concreting without breaking the seal provided by the concrete cover over the discharge end. Should this seal is broken, the tremie should be lift and plugged before concreting is recommended. The tremie should never be moved laterally though freshly placed concrete. It should be lifted vertically above the surface of concrete and shifted to its new position.

When large quantities of concrete are to be placed continuously, it is preferable to place concrete simultaneously and uniformly through a battery of tremies, rather than shift a single tremies from point to point. It has been recommended that the spacing of tremies be between 3.5 and 5m and that the end tremies should be about 2.5m from the formwork. The risk of segregation and non-uniform stiffening can be minimized by maintaining the surface of concrete in the forms as level as possible and by providing a continuous and rapid flow of concrete.

Method of underwater concreting - Tremie method (inside view)



Basic principle behind Method of
underwater concreting - Tremie method

2. **Dump bucket placing**

This method has the advantage that concreting can be carried out at considerable depths. The dump buckets are usually fitted with drop-bottom or bottom-roller gates which open freely outward when tripped. The bucket is completely filled with concrete and its top covered with a canvas cloth or a gunny sack to prevent the disturbance of concrete as the bucket is lowered into water. Some buckets are provided with a special base which limits the agitation of the concrete during discharge and also while the empty bucket is hoisted away from the fresh concrete. The bucket is lowered by a crane up to the bottom surface of concrete and then opened either by divers or by a suitable arrangement from the top. It is essential that the concrete be discharged directly against the surface on which it is to be deposited. Early discharge of bucket, which permits the fresh concrete to drop through water must be avoided. The main disadvantage of the bucket method is the difficulty in keeping the top surface of the placed concrete reasonably level. The method permits the use of slightly stiffer concrete than does tremie method

3. **Placing in bags**

The method consists partially filling of cloth or gunny sacks with concrete, and tying them in such a way that they can readily be accommodated in a profile of the surface on which they are placed. The properly filled bags are lowered into water and placed carefully in a header-and-stretcher fashion as in brick masonry construction with the help of divers.

The method has advantages in that, in many cases, no formwork is necessary and comparatively lean mixes may be used provided sufficient plasticity is retained. On the other hand, as the accurate positioning of the bags in place can be only accomplished by the divers, the work is consequently slow and laborious. Voids between adjacent bags difficult to fill, there is little bonding other than that achieved by mechanical interlock between bags. The bags and labour necessary to fill and tie them are relatively expensive, and the method is only suited for placing the concrete in rather shallow water.

4. **Prepacked concrete**

This technique also called *grouted concrete*, consists of placing the coarse aggregate only in the forms and thoroughly compacting it to form a prepacked mass. This mass is then grouted with the cement mortar of the required proportions. The aggregate should be wetted before being placed in position. The mortar that grouts the concrete displaces water and fills the voids.

The aggregate should be well graded to produce a dense and compact concrete. Aggregates up to a maximum size of 80mm can be conveniently used. The coarse aggregate may also be allowed to fall from heights of up to 4 meters, without causing any appreciable segregation.

The mortar consists of fine sand, pozzolanic filler material and a chemical agent, which serves

(i) To help the penetration,

(ii) To inhibit early setting of cement,

(iii) To aid the dispersion of the particles, and

(iv) To increase the fluidity of mortar.

An air-entraining agent is also added to the mortar to entrain about 4 per cent of air. A small variation of the procedure of preparation of the cement mortar for grouting leads to a process called *colcrete*. In this process the mortar grout is prepared in a special high speed mixer. No admixtures are used in this process. The high speed mixing produces a very fluid grout which is immiscible with water. The maximum size of the sand used is 5mm and the sand should be well graded. The mix ratio ranges from 1:1.5 to 1:4 with a water-cement ratio of about 0.45.

MASS CONCRETE

The concrete placed in massive structures like dams, canal locks, bridge piers, etc. can be termed as *mass concrete.* A large size aggregate (up to 150mm maximum size) and a low slump (stiff consistency) are adopted to reduce the quantity of cement in the mix to about 5 bags per cubic meter of mass concrete. The mix, being relatively harsh and dry, requires power vibrators of immersion type for compaction.

The concrete is generally placed in open forms. Because of the large mass of the concrete, the heat of hydration may lead to a considerable rise of temperature. Placing the concrete, in shorter lifts allowing several days before the placement of the next lift of concrete can help in the dissipation of heat. Circulation of cold water through the pipes buried in the concrete mass may prove useful. Alternatively, where possible concreting can be done in the winter season such that the peak temperature in concrete can be lowered, or the aggregates may be cooled before use.

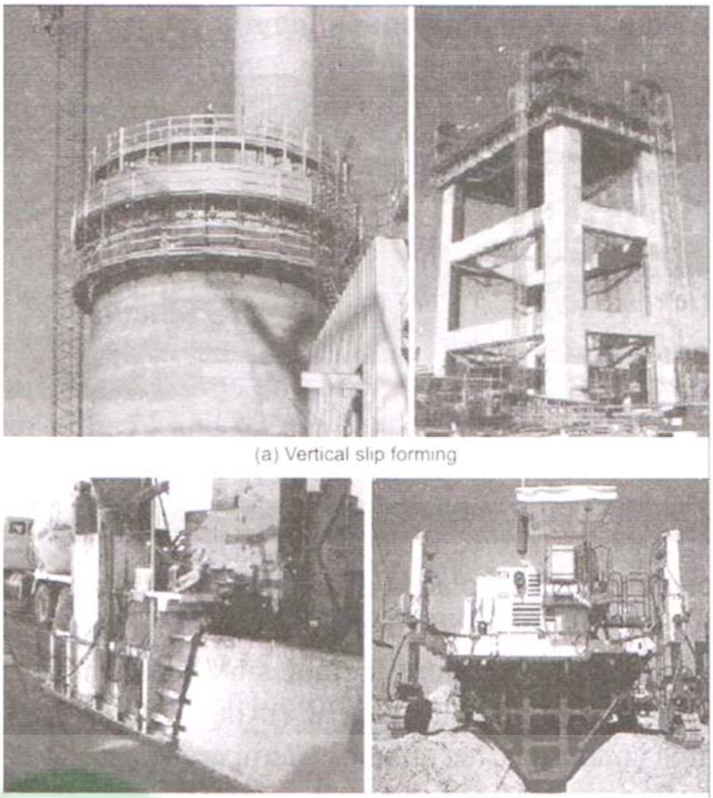
The high temperature of mass concrete due to the heat of hydration may lead to extensive and serious shrinkage cracks. The shrinkage cracks can be prevented by using low heat cement and by continuous curing of concrete. The mass concrete develops high early strength but later age strength is lower than that of continuously cured concrete at normal temperatures. The volume changes of mass concrete during setting and hardening are small, but the concrete is susceptible to large creep at later ages.

SLIP-FORMING TECHNIQUE

The slip-form method, developed by Swedish Technologies for constructing chimneys, cooling towers, etc. refers to the continuously moving form, moving along the project at such a speed that the previously poured concrete has already achieved enough strength to support the vertical pressure from the concrete still in the form and to withstand lateral pressure caused by wind, inclination of walls, and so on.

The vertical slip-form relies on the quick-setting properties of concrete requiring a balance between early strength gain and workability. Concrete needs to be workable enough to be placed to the formwork and strong enough to develop early strength so that the form can slip upwards without any disturbance to the freshly placed concrete.

Slip-forming utilizes a mechanized moving-work platform system enabling semi- continuous placement of concrete. All concreting operations like the placing of reinforcement, installation of all block-outs and fixtures, pouring of concrete as well as finishing and inspection of concrete surfaces are performed gradually from work platforms which are attached permanently to the slip-forms and thus move together with the forms.



(a) Vertical slip forming

(i) Slip forming a wall (ii) Slip forming canal paving

(b) Horizontal slip forming

The slip-forms and work platforms are raised by hydraulic jacks spaced at equal intervals which climb on vertical steel rods or tubes. All jacks are operated simultaneously and they lift the slip-form in increments of 25 mm every three to 12 minutes, depending on the required sliding speed. An average sliding speed of 250 mm an hour may be achieved during construction.

Since in the slip-form construction, the concrete is poured continuously, there are no cold joints and surface colour is uniform. This results in a strong and esthetically attractive surface. Once the forms have been built, a 50 m tall slip-form can take approximately five days to pour.

A vertical slip forming illustrated in Fig. (a) And (b) is the fastest and most efficient method of casting vertical reinforced concrete walls in many types of structures.

Horizontal slip forming technique has been very successful in concrete highway and runway pavement construction. There are two basic methods of slip-forming concrete pavement, namely, the fixed-form paving and slip-form paving. Fixed-form paving requires the use wooden or metal side forms that are set up along the perimeter of the pavement before paving. Slip-form paving does not require any steel or wooden forms. As the slip-form paving machine moves forward, the attached sliding forms also move along, thus fixing of forms beforehand and re- moving' them afterward as paving is not required in fixed-form. After the fixed-form or slip-form equipment has passed through, the hand-tools are used to further finish the slab.

The combination of a Well-designed slip-form system and quality concrete pump performance has enabled this method of construction used typically on large-scale storage silos and other vertical concrete structures, such as nuclear shield walls, high-rise buildings chimneys, bridge piers, dams.

PREFABRICATION TECHNOLOGY

Prefabrication is the practice of assembling components of a structure in a factory or other manufacturing site, and transporting complete assemblies or sub-assemblies to the construction site where the structure is to be located. The term is used to distinguish this process from the more conventional construction practice of transporting the basic materials to the construction site where all assembly is carried out.

The theory behind the method is that time and cost is saved if similar construction tasks can be grouped, and assembly line techniques can be employed in prefabrication at a location where skilled labour is available, while congestion at the assembly site, which wastes time, can be reduced. The method finds application particularly where the structure is composed of repeating units or forms, or where multiple copies of the same basic structure are being constructed.

The most widely used form of prefabrication in building and civil engineering is the use of prefabricated concrete and prefabricated steel sections in structures where a particular part or form is repeated many times.

Pouring concrete sections in a factory brings the advantages of being able to re-use moulds and the concrete can be mixed on the spot without having to be transported to and pumped wet on a congested construction site. Prefabricating steel sections reduces on-site cutting and welding costs as well as the associated hazards.

Prefabrication saves engineering time on the construction site in civil engineering projects. This can be vital to the success of projects such as bridges and avalanche galleries, where weather conditions may only allow brief periods of construction. Prefabricated bridge elements and systems offer bridge designers and contractors significant advantages in terms of construction time, safety, environmental impact, constructibility, and cost. Prefabrication can also help minimize the impact on traffic from bridge building. Additionally, small, commonly used structures such as concrete pylons are in most cases prefabricated.

Aims of Prefabrication

- To speed up the construction time.
- To lower the labour cost.
- To allow the year round construction.
- To ensure precise conformity to building codes, standards and greater quality assurance.
- To allow less wastage of materials than n in site- built construction.
- to ensure higher worker safety and comfort level than in site- built construction

Limitations of prefabrication

- A small number of units required may prove to be uneconomical
- Special connections, such as special bearings to transmit the vertical and horizontal loads, can add cost to the system
- Waterproofing at joints
- Transportation difficulties
- Need for cranes

Advantages

1. Mass production of units:
   - Automation of manufacturing process can save labour and reduce price.
   - Designers can get used to the standard units and have ready access to details.
2. Reduction of costs and construction time on site:
   - Less work to be done on site.
   - Saving in the use of formwork on site
   - Precast units can be erected in bad weather.
3. Effective use of formwork:
   - Steel formwork is normally used and increases the number of use to 200 times.
   - Precast unit can be shaped so that they are self- stripping and this means the reduction in labour and wear on moulds.
4. Improved quality of units.
   - Factory production under strict quality control.

- Precast units can be closely checked after manufacture.
- Units can be cast in any position, such as upside down, on their sides, etc.
- Colored concrete can be produced by using white cement and the color pigments.

5. Casting under cover.
   - Protection from drying winds.
6. Demountable structures
   - Bolted connections can be easily dismantled and re- erected in other places.
7. Construction over and under water
   - No or little formwork is required.
   - False work is not required.
   - Minimal disruption to traffic.
8. Casting of units before the site becomes available
   - Units can be casted and stocked up before the site becomes available which can shorten the construction time.
9. Built-in services and insulation.
   - services and insulation can be built in to precast units accurately in the factory
10. Use of semi-skilled labour
11. Accelerated curing techniques.
    - Higher turnover per mould and plant.
    - Controlled curing results in more durable units.
12. Solution to the problem of lack of local resources and labour.
    - Units can be produced thousands of kilometers away from the site.

Disadvantages

- Leaks can form at joints in prefabricated components.
- Transportation costs may be higher for voluminous prefabricated sections than for the materials of which they are made, which can often be packed more efficiently.
- Large prefabricated sections require heavy-duty cranes and precision measurement and handling to place in position.
- Larger groups of buildings from the same type of prefabricated elements tend to look drab and monotonous.

Applications

In India, Pre-engineered building systems find application primary in the construction of rural as well as urban, individual & mass housing projects, farmhouses, slum reorganization projects and rehabilitation projects, amenity structures like health centres, kiosks, primary schools, panchayat ghars, etc.

The recent focus has also shifted to cover composite construction for R&D facilities, the pharmacy industry and exhibition centres, and functional requirements like offices, seminar halls, call centres supermarkets, showrooms, etc.

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Prepared By

NAJEEB. M

Assistant Professor
Dept. of Civil Engineering
MEA Engineering College