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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

UNIT – I – ADVANCED CONCRETE TECHNOLOGY– SCIA7001

UNIT I

CONCRETE MAKING MATERIALS

Cement – Manufacture – Types of cement – OPC, PPC, GBFSC – Grades of Cement, 33, 43 & 53 – Hydration process – Aggregates – Classification – Sources – Bulking of sand – Measurement of moisture content –Thermal properties – Qualities of water for concreting.

Cement is the mixture of calcareous, siliceous, argillaceous and other substances.

Cement is a hydraulic binder and is defined as a finely ground inorganic material which, when mixed with water, forms a paste which sets and hardens by means of hydration reactions and processes which, after hardening retains it's strength and stability even under water.

Functions of cement:

- Popular as building material.
- Material with adhesive & cohesive properties.
- To bind the fine & coarse aggregate together
- To fill voids in between fine & coarse aggregate particle form a compact mass.

Composition of Cement

- Lime Calcium Oxide (CaO) = 60 – 65% (63%)
- Silica (SiO2) = 20 – 25% (22%)
- Aluminum Oxide = 4 - 8% (6%)
- Iron Oxide = 2 – 4 % (3%)
- Magnesium Oxide = 1 – 3 %
- Gypsum 1 to 4%

Types of cement - OPC, PPC, GBFSC

ORDINARY PORTLAND CEMENT:

it 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.

It is made by finely clinker produced by calcining to incipient fusion a mixture of argillaceous and calcareous materials: Limestone + Shale/Clay + Heat = Clinker +CKD + Exit Gas

OPC is environment friendly as well as economical

Ordinary Portland Cement is available in 3 grades - OPC-53, OPC-43, OPC-33

OPC-43 GRADE

The 43 grade OPC is the most popular general-purpose cement in the country today. The production of 43 grade OPC is nearly 50% of the total production of cement in the country.

Grade 53 means a compression strength of 53 N/ mm2 is attained on its mortar with sand after a curing period of 28 days. Same will apply to grade 43 and 33.OPC cement is used when where High Early Strength is required and for constructing high-rise buildings. It attains early strength and is fast setting, but has increased chances of micro cracking.

Advantages of OPC:

- Produces highly durable and sound concrete due to very low percentage of alkalis, chlorides, magnesia and free lime in its composition.
- Almost negligible chloride content results in restraining corrosion of concrete structure in hostile environments.
- Significant saving in cement consumption while making concrete of grades M15, M20, M25, M35 and pre-cast segments due to high strength.

For PPC cement there is only one grade which gives a minimum compressive strength of 33 MPa after 28 days when mixed with standard sand.

PPC cement is used where Extra Durability is required and is preferred in mass construction.

PORTLAND POZZOLANA CEMENT (PPC) is manufactured by the inter-grinding of ORDINARY PORTLAND CEMENT clinker with 15 to 35% of pozzolanic material. The Portland Pozzolana Cement is a kind of Blended Cement which is produced by either intergrinding of OPC clinker along with gypsum and pozzolanic materials in certain proportions or grinding the OPC clinker, gypsum and Pozzolanic materials separately and thoroughly blending them in certain proportions.

Pozzolana is a natural or artificial material containing silica in a reactive form. It may be further discussed as siliceous or siliceous and aluminous material which in itself possesses little, or no cementitious properties but will in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. It is essential that pozzolana be in a finely divided state as it is only then that silica can combine with calcium hydroxide (liberated by the hydrating Portland Cement) in the presence of water to form stable calcium silicates which have cementitious properties. The pozzolanic materials commonly used are:

i. Volcanic ash
ii. Calcined clay
iii. Fly ash- The ash produced at thermal power stations by burning of coal and lignite is known as *fly ash*.
iv. Silica fumes - Silica fume is a byproduct in the carbothermic reduction of high-purity quartz with carbonaceous materials like coal, coke, wood-chips, in electric arc furnaces in the production of silicon andferrosilicon alloys.

It is made by mixing substances containing Calcium Carbonate such as chalk / limestone, with substances containing silica , alumina and iron oxide such as clay/ shale.

•Clay/shale: SiO_2 Silica (silicon oxide) abbreviated S

Fe_2O_3 Ferrite (iron oxide) abbreviated F

Al_2O_3 Alumina (aluminium oxide) abbreviated A

Limestone/chalk $CaCO_3$ Calcium carbonate abbreviated C

then the mixture heated and became clinker.

Clinker is then grounded to powder.

The hardening Portland cement is a chemical process during which heat is evolved.

Why is it called "portland" cement?

Joseph Aspdin, an English mason who patented the product in 1824, named it portland cement because it produced a concrete that resembled the color of the natural limestone quarried on the Isle of Portland, a peninsula in the English Channel

Advantages of PPC:

- Higher durability of concrete structure due to less permeability of water.
- More resistance towards the attack of alkalies, sulphates, chlorides, chemicals.
- Better work ability.
- Low heat of hydration.
- Due to high fineness, PPC has better cohesion with aggregates and makes more dense concreteness.
- Comparative lower Water-Cement ratio provides an added advantage for the further increase of compressive strength of the concrete.
- Better surface finish.

Ground-granulated blast-furnace slag (**GGBS** or **GGBFS**) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. The main components of blast furnace slag are CaO (30-50%), SiO_2 (28-38%), Al_2O_3 (8-24%), and MgO (1-18%)

Two major uses of GGBS are in the production of quality-improved slag cement, namely Portland Blast furnace cement (PBFC) and high-slag blast-furnace cement (HSBFC), with GGBS content ranging typically from 40 to 50%; and in the production of ready-mixed or site-batched durable concrete. Concrete made with GGBS cement sets more slowly than concrete made with ordinary Portland cement, depending on the amount of GGBS in the cementitious material, but also continues to gain strength over a longer period in production conditions. This results in lower heat of hydration and lower temperature rises, and makes avoiding joints easier, but may also affect construction schedules where quick setting is required.

Concrete containing GGBS cement has a higher ultimate strength than concrete made with Portland cement. It has a higher proportion of the strength-enhancing calcium silicate hydrates (CSH) than concrete made with Portland cement only, and a reduced content of free lime, which does not contribute to concrete strength. Concrete made with GGBS continues to gain strength over time, and has been shown to double its 28-day strength over periods of 10 to 12 years.

Since GGBS is a by-product of steel manufacturing process, its use in concrete is recognized by LEED etc. as improving the sustainability of the project and will therefore add points towards LEED certification.

MANUFACTURE OF PORTLAND CEMENT:-

1) Raw Materials

2) Crushing & Grinding of Raw Materials

3) Type of cement processes:

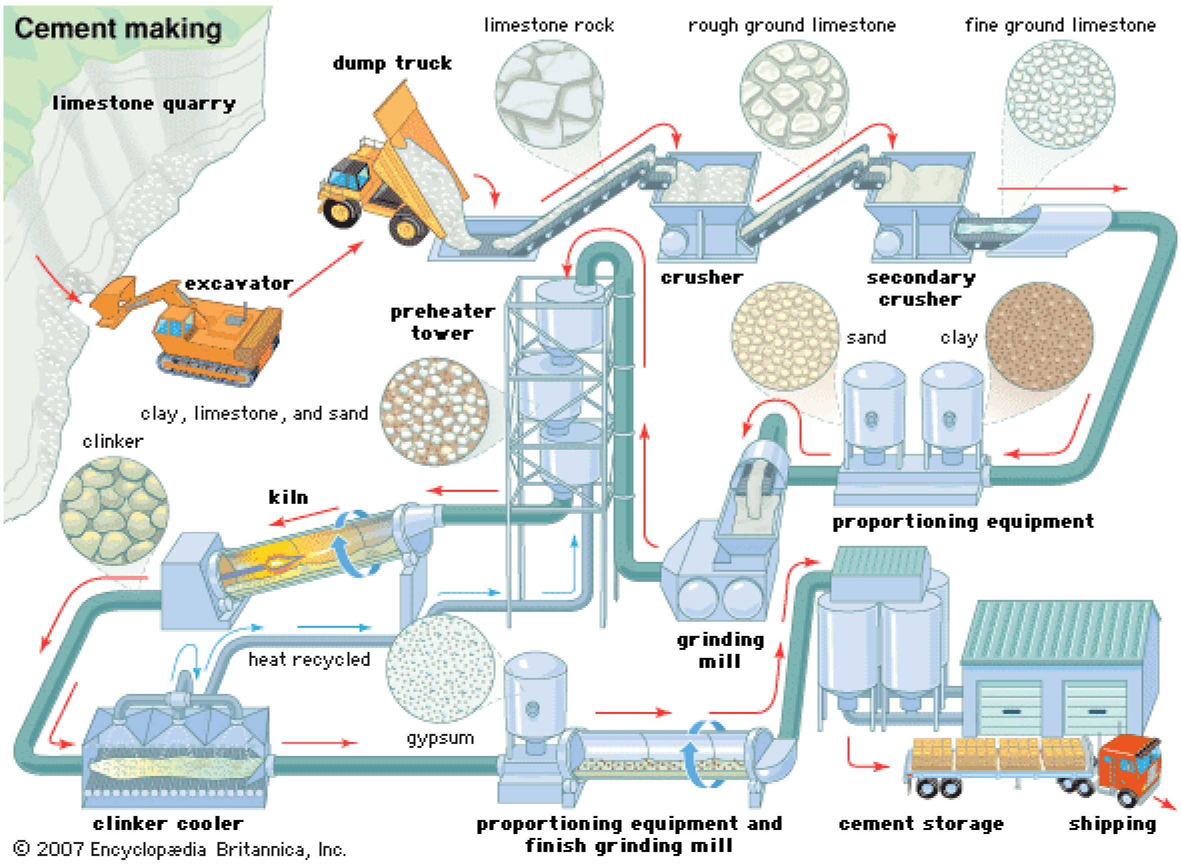
   a)Wet Process

   b)Dry process

4) Burning Process

5) Grinding

6) storage, packing, dispatch



1. Raw Material Extraction

Cement uses raw materials that cover calcium, silicon, iron and aluminum. Such raw materials are limestone, clay and sand. Limestone is for calcium. It is combined with much smaller proportions of sand and clay. Sand & clay fulfill the need of silicon, iron and aluminum.

2. Quarrying, Dredging, and Digging

Quarrying of limestone and shale is accomplished by using explosives to blast the rocks from the ground. After blasting, huge power shovels are used to load dump trucks or small railroad cars for transportation to the cement plant, which is usually nearby.

The ocean floor is dredged to obtain the shells, while clay and marl are dug out of the ground with power shovels. All of the raw materials are transported to the plant.

3. Grinding

After the raw materials have been transported to the plant, the limestone and shale which have been blasted out of the quarry must be crushed into smaller pieces. Some of the pieces, when blasted out, are quite large. The pieces are then dumped into primary crushers which reduce them to the size of a softball. The pieces are carried by conveyors to secondary crushers which crush the rocks into fragments usually no larger than 3/4 inch across.

4. Blending

After the rock is crushed, plant chemists analyze the rock and raw materials to determine their mineral content. The chemists also determine the proportions of each raw material to utilize in order to obtain a uniform cement product. The various raw materials are then mixed in proper proportions and prepared for fine grinding.

5. Fine Grinding

When the raw materials have been blended, they must be ground into a fine powder. This may be done by one of two methods:

- Wet process, or
- Dry process

The wet process of fine grinding is the older process, having been used in Europe prior to the manufacture of cement in the United States. This process is used more often when clay and marl, which are very moist, are included in the composition of the cement. In the wet process, the blended raw materials are moved into ball or tube mills which are cylindrical rotating drums which contain steel balls. These steel balls grind the raw materials into smaller fragments of up to 200 of an inch. As the grinding is done, water is added until a slurry (thin mud) forms, and the slurry is stored in open tanks where additional mixing is done. Some of the water may be removed from the slurry before it is burned, or the slurry may be sent to the kiln as is and the water evaporated during the burning.

The dry process of fine grinding is accomplished with a similar set of ball or tube mills; however, water is not added during the grinding. The dry materials are stored in silos where additional mixing and blending may be done.

6. Burning

Burning the blended materials is the key in the process of making cement. The wet or dry mix is fed into the kiln, which is one of the largest pieces of moving machinery in the industry. It is generally twelve feet or more in diameter and 500 feet or more in length, made of steel and lined with firebrick. It revolves on large roller bearings and is gradually slanted with the intake end higher than the output end.

As the kiln revolves, the materials roll and slide downward for approximately four hours. In the burning zone, where the heat can reach 3,000 degrees Fahrenheit, the materials become incandescent and change in color from purple to violet to orange. Here, the gases are driven from the raw materials, which actually change the properties of the raw materials. What emerges is “clinker” which is round, marble-sized, glass-hard balls which are harder than the quarried rock. The clinker is then fed into a cooler where it is cooled for storage.

7. Finish Grinding

The cooled clinker is mixed with a small amount of gypsum, which will help regulate the setting time when the cement is mixed with other materials and becomes concrete. Here again there are primary and secondary grinders. The primary grinders leave the clinker , ground to the fineness of sand, and the secondary grinders leave the clinker ground to the fineness of flour, which is the final product ready for marketing.

8. Packaging/Shipping

The final product is shipped either in bulk (ships, barges, tanker trucks, railroad cars, etc.) or in strong paper bags which are filled by machine. In the United States, one bag of Portland cement contains 94 pounds of cement, and a “barrel” weighs four times that amount, or 376 pounds. In Canada, one bag weighs 87 1/2 pounds and a “barrel” weighs 350 pounds.
Masonry cement bags contain only seventy pounds of cement.
When cement is shipped, the shipping documents may include “sack weights.” This must be verified by the auditor since only the cement is taxable. “Sack weights” must be excluded.

Aggregate is a granular material, such as sand, gravel, crushed stone, crushed hydraulic-cement concrete, or iron blast-furnace slag, used with a hydraulic cementing medium to produce either concrete or mortar.

Coarse Aggregate

Those particles that are predominantly retained on the 4.75 mm (No. 4) sieve, are called **coarse aggregate**

Fig. Coarse aggregate **fig. fine aggregate**

Fine Aggregate

Those particles passing the 9.5 mm (3/8 in.) sieve, almost entirely passing the 4.75 mm (No. 4) sieve, and predominantly retained on the 75 μm (No. 200) sieve are called fine aggregate

Purpose & Uses

1. Increases the volume of concrete, thus reduces the cost
2. Provide dimensional stability
3. Influence hardness, abrasion resistance, elastic modulus and other properties of concrete to make it more durable, strong and cheaper.

Classification of Aggregates

class	examples	uses
ultra-lightweight <1300 kg/m3	vermiculite ceramic spheres perlite	lightweight concrete which can be sawed or nailed, also for its insulating properties
Lightweight 1300-1850 kg/m3	Natural – pumice, diatomite, scoria, volcanic cinders, saw dust, rice husk Artificial – cinders, coak breeze (burnt fine coal), foamed slag, bloated clay (expanded clay), expanded shales and slate, sintered flyash, thermocoal beads	used primarily for making lightweight concrete for structures, also used for its insulating properties.
normal weight 2000-2600 kg/m3	**Natural** – sand, gravel, crushed rock such as granite, quartzite, basalt, sandstone **Artificial** – broken brick, recycled concrete, sintered flyash, bloated clay and air cooled slag	used for normal concrete projects
Heavyweight 3500 kg/m3	Barites, magnetites, lead shots, steel or iron shot, and steel or iron pellets	used for making high density concrete for shielding against nuclear radiation and in offshore structures

Sources of aggregates

Aggregates are derived from three different sources –

a. **Igneous rocks :** aggregates from this type are found to be hard, tough, dense and chemically active
b. **Sedimentary rocks :** Aggregates are flaky, soft to hard, porous to dense and light to heavy
c. **Metamorphic rocks** : Aggregates of both properties of igneous and sedimentary rocks are found eg. Gneiss and quartzite.

Bulking of Sand:

The volume increase of fine aggregate due to presence of moisture content is known as ***bulking***. Fine sand bulks more as compared to coarse sand. Extremely fine sand particularly the manufactured fine aggregate bulks as much as about 40%.Fine aggregate do not show any bulking when it is absolutely dry or completely saturated.

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

Bulking of aggregate is dependent upon two factors,

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

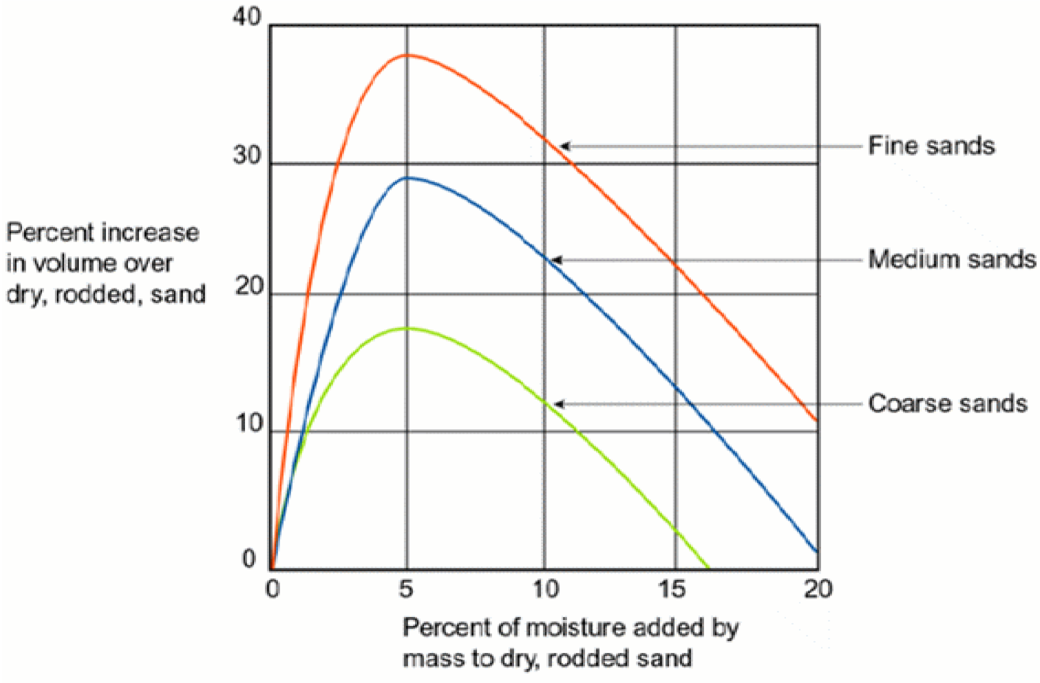
Bulking increases with increase in moisture content upto a certain limit and beyond that the further increase in moisture content results in decrease in volume as shown in fig below. When the fine aggregate is completely saturated it does not show any bulking. Fine sand bulks more as compared to coarse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

If care is not given to the effect of bulking, in the case of volume batching, the resulting concrete is likely to be under-sanded and harsh. It will also affect the yield of concrete for a given cement content.

Determination of Bulking of Sand:

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

Fill a sample of moist fine aggregate (sand) into a measuring cylinder. Note down the level, say $\mathbf{h_1}$



percentage of bulking of sand with moisture content.

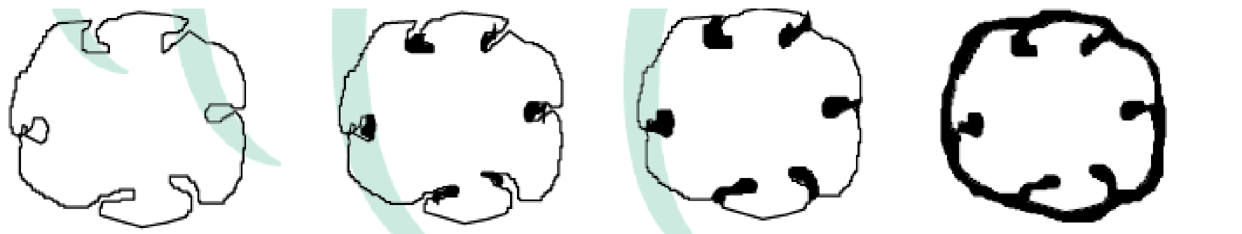
- Pour water into a measuring cylinder upto top surface of sand and completely cover the sand with water and shake it. Since the volume of the saturated sand is the same as that of the dry sand, the saturated sand completely counteract the bulking effect. Note down the level of sand, say $\mathbf{h_2}$.
- Subtract the final level h2 from initial level h1 (i.e. $\mathbf{h_1\text{-}h_2}$), which shows the bulking of sand under test.
- Calculate percentage of bulking using formula given below.
- Percentage of bulking = $\mathbf{[(h_1-h_2)/h_2]*100}$

Moisture Content in aggregate

It is required to determine the moisture content in aggregate to adjust the water content in concrete mixing as per the mix proportions depending upon the various grades. The moisture is absorbed by the pores and adsorbed on the surface of aggregates either from air or during rains.

Around 1% and 10% of surface moisture is found in coarse and fine aggregate respectively.

The moisture content of the aggregate is defined at four states. When the aggregate has no moisture on the surface or the interior pores then the aggregate is in a dry (sometimes called oven-dry) state. When some of the interior pores of the aggregate are filled with water and there is no moisture on the surface then the aggregate is in an air-dry state. When all the interior pores of the aggregate are filled with water but there is no moisture on the surface then the aggregate is in a saturated-surface-dry (SSD) state. When all the interior pores of the aggregate are filled with water and there is moisture on the surface then the aggregate is in a wet state. The dry (oven-dry) and SSD conditions are not typically found for aggregate in storage, but are used as the basis for moisture content measurements and associated calculations.



Dry (oven dry) Aggregate (contains no water) | Air-dry Aggregate (partially absorbed water) | Saturated-Surface-Dry Aggregate (SSD) (absorbed water) | Wet Aggregate (Absorbed + free surface moisture)

Some of the methods that are being used for determination of moisture content of aggregate are given below:

- Drying Method
- Calcium Carbide Method
- Automatic measurement
- Displacement Method
- Measurement by electrical meter

Drying Method

The application of drying method is fairly simple. Drying is carried out in an oven and the loss in weight before and after drying will give the moisture content of the aggregate. If the drying is done completely at a high temperature for a long time, the loss in weight will include not only the surface water but also some absorbed water. Appropriate corrections may be made for the saturated and surface dry condition. The oven drying method is too slow for field use. A fairly quick result can be obtained by heating the aggregate quickly in an open pan. The process can also be seeded up by pouring inflammable liquid such as methylated spirit or acetone over the aggregate and igniting it.

Calcium Carbide Method

A quick and reasonably accurate method of determining the moisture content of fine aggregate is to mix it with an excess of calcium carbide in a strong air-tight vessel fitted with pressure gauge. Calcium carbide reacts with surface moisture in the aggregate to produce acetylene gas. The pressure of acetylene gas generated depends upon the moisture content of the aggregates. The pressure gauge is calibrated by taking a measured quantity of aggregate of known moisture content and then such a calibrated pressure gauge could be used to read the moisture content of aggregate directly. This method is often used to find out the moisture content of fine aggregate at the site of work. The equipment consists of a small balance, a standard scoop and a container fixed with dial gauge. The procedure is as follows: Weigh 6 grams of representative sample of wet sand and pour it into the container. Take one scoop full of calcium carbide powder and put it into the container. Close the lid of the container and shake it rigorously. Calcium carbide reacts with surface moisture and produces acetylene gas, the pressure of which drives the indicator needle on the pressure gauge. The pressure gauge is so calibrated, that it gives directly percentage of moisture. The whole job takes only less than 5 minutes and as such, this test can be done at very close intervals of time at the site of work.

Displacement Method

In the laboratory the moisture content of aggregate can be determined by means of pycnometer or by using Siphon-Can Method. The principle made use of is that the specific gravity of normal aggregate is higher than that of water and that a given weight of wet aggregate will occupy a greater volume than the same weight of the aggregate when dry. By knowing the specific gravity of the dry aggregate, the specific gravity of the wet aggregate can be calculated. From the difference between the specific gravities of the dry and wet aggregates, the moisture content of the aggregate can be calculated.

The water content (w) of the sample is obtained as

$$w = \left[\frac{M_2 - M_1}{M_3 - M_4} \left(\frac{G - 1}{G} \right) - 1 \right] \times 100$$

Where M_1=mass of empty Pycnometer,

M_2= mass of the Pycnometer with wet soil

M_3= mass of the Pycnometer and soil, filled with water,

M_4 = mass of Pycnometer filled with water only.

G= Specific gravity of aggregate

Electrical Meter Method

Recently electrical meters have been developed to measure instantaneous or continuous reading of the moisture content of the aggregate. The principle that the resistance gets changed with the change in moisture content of the aggregate has been made use of. In some sophisticated batching plant, electrical meters are used to find out the moisture content and also to regulate the quantity of water to be added to the continuous mixer.

Automatic Measurement

In modern batching plants surface moisture in aggregates is automatically recorded by means of some kind of sensor arrange that the element. The arrangement is made in such a way that the quantity of free water going with aggregate is automatically recorded and simultaneously that much quantity of water is reduced.

Thermal properties of aggregate

The linear thermal coefficient of expansion ranges from about 5 x 10^{-6} per °C to 13 x 10^{-6} per °C for aggregates and 11 x 10^{-6} per °C to 16 x 10^{-6} per °C for hydrated cement.

If the thermal expansion of hydrated cement paste differs too much with that of aggregates, then a high change in temperature causes diffential movement and a break in bond between the aggregate particles and surrounding hardened paste.

Rock and aggregate possesses three thermal properties which are significant in establishing the quality of aggregate for concrete constructions.

They are:

(i) Coefficient of expansion

(ii) Specific heat

(iii) Thermal conductivity

The ideal temperature for the promotion of alkali-aggregate reaction is in the range of 10 to 38°C. If the temperatures condition is more than or less than the above, it may not provide an ideal situation for the alkali-aggregate reaction.

Out of these, specific heat and conductivity are found to be important only in mass concrete construction where rigorous control of temperature is necessary. Also these properties are of consequence in case of light weight concrete used for insulation purpose.

When we are dealing with the aggregate in general it will be sufficient at this stage to deal with only the coefficient of expansion of the aggregate, since it interacts with the coefficient of thermal expansion of cement paste in the body of the set-concrete.

- An average value of the linear thermal coefficient of expansion of concrete may be taken as 9.9 x 10–6 per °C, but the range may be from about 5.8 x 10–6 per °C to 14 x 10–6 per °C depending upon the type and quantities of the aggregates, the mix proportions and other factors.
- The range of coefficient of thermal expansion for hydrated cement paste may vary from 10.8 x 10–6 Per °C to 16.2 x 10–6 per °C.
- Similarly, for mortar it may range from 7.9 x 10–6 per °C to 12.6 x 10–6 per °C.

Type of aggregate	**Coefficient of therma expansion 10–6 per °C**
Gabbro	3.6 – 9.7
Granite	1.8 – 11.9
Marble	1.1 – 16
Dolamite	6.7 – 8.6
Sandstone	11.7
Limestone	0.9-12.2
Portland stone	7.4
Blast furnace slag	10.6
Foamed slag	12.1

Hydration Process

Portland cement is a hydraulic cement, hence it derives its strength from chemical reactions between the cement and water. The process is known as hydration.

Hardened paste consists of the following:

Ettringite - 15 to 20%
Calcium silicate hydrates, CSH - 50 to 60%
Calcium hydroxide (lime) - 20 to 25%
Voids - 5 to 6% (in the form of capillary voids and entrapped and entrained air)

Each of the following four main cement minerals reacts at a different rate and tends to form different solid phases when it hydrates.

i. Hydration of alite (Tricalcium silicate):

Tricalcium silicate (C3S) is the most abundant and important cement mineral in Portland cements. It hardens rapidly and largely responsible for initial setting and early strength. A higher percentage of this compound will produces higher heat of hydration and accounts for faster and high early strength.

The hydration of C_3S can be written as:

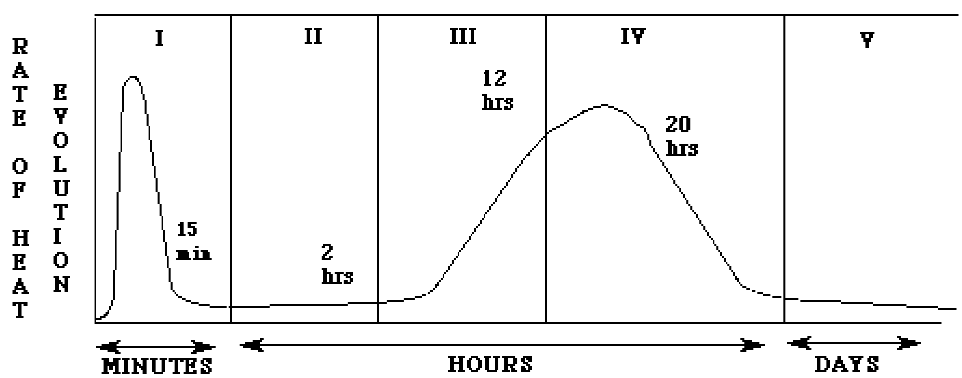
$$\mathbf{2C_3S + 6H \rightarrow C_3S_2H_3 + 3CH + 120\ Cal/g \uparrow}$$

Tricalcium silicate (Alite) + Water → Calcium Silicate Hydrate (CSH) gel + Calcium Hydroxide (lime) + Heat

Upon the addition of water, tricalcium silicate rapidly reacts to release calcium ions, hydroxide ions, and a large amount of heat. The pH quickly rises to over 12 because of the release of alkaline hydroxide (OH^-) ions. This initial hydrolysis slows down quickly after it starts resulting in a decrease in heat evolved.

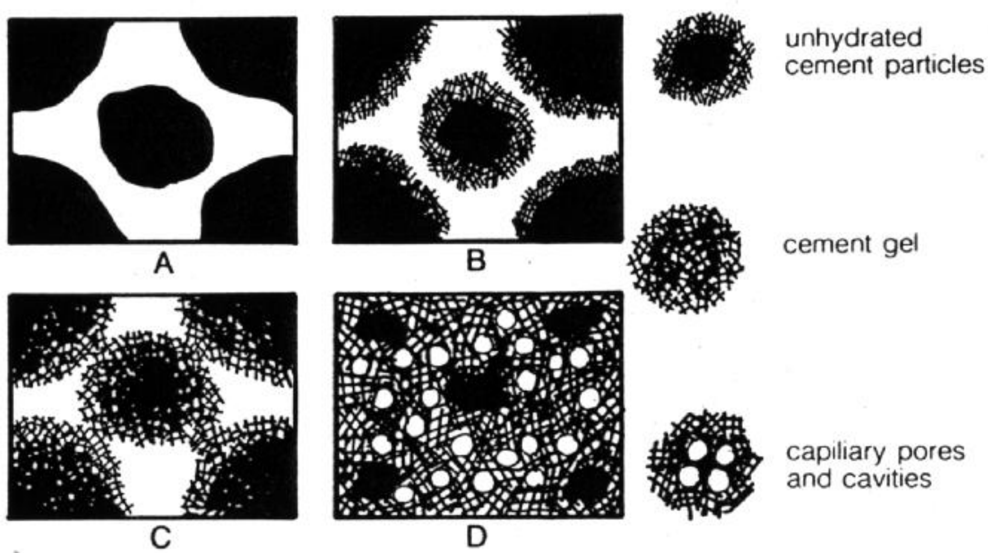
The CSH has a short-networked fiber structure which contributes greatly to the initial strength of the cement glue. The calcium silicate hydrates contribute to the strength of the cement paste. This reaction generates less heat and proceeds at a slower rate, meaning that the contribution of C_2S to the strength of the cement paste will be slow initially. This compound is however responsible for the long-term strength of portland cement concrete.

The reaction slowly continues producing calcium and hydroxide ions until the system becomes saturated. Once this occurs, the calcium hydroxide starts to crystallize. Simultaneously, calcium silicate hydrate begins to form. Ions precipitate out of solution accelerating the reaction of tricalcium silicate to calcium and hydroxide ions. (Le Chatlier's principle). The evolution of heat is then dramatically increased as shown in fig below



Rate of heat evolution during the hydration of portland cement

The formation of the calcium hydroxide and calcium silicate hydrate crystals provide "seeds" upon which more calcium silicate hydrate can form. The calcium silicate hydrate crystals grow thicker making it more difficult for water molecules to reach the unhydrated tricalcium silicate. The speed of the reaction is now controlled by the rate at which water molecules diffuse through the calcium silicate hydrate coating. This coating thickens over time causing the production of calcium silicate hydrate to become slower and slower.



A) Immediately after mixing

B) Reaction around particles – early stiffening

C) Formation of skeletal structure – first hardening

D) Gel infilling – later hardening

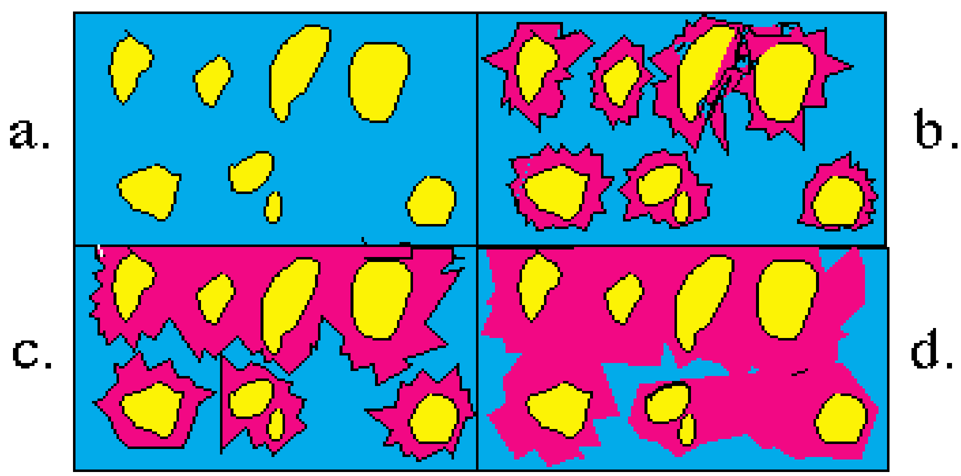


Fig. Schematic illustration of different stages of hydration.

The above diagrams represent the formation of pores as calcium silicate hydrate is formed. Note in diagram (a) that hydration has not yet occurred and the pores (empty spaces between grains) are filled with water. Diagram (b) represents the beginning of hydration. In diagram (c), the hydration continues. Although empty spaces still exist, they are filled with water and calcium hydroxide. Diagram (d) shows nearly hardened cement paste. Note that the majority of space is filled with calcium silicate hydrate. That which is not filled with the hardened hydrate is primarily calcium hydroxide solution. The hydration will continue as long as water is present and there are still unhydrated compounds in the cement paste.

ii. Hydration of Dicalcium silicate (Belite) :

$$\mathbf{2C_2S + 4H \rightarrow C_3S_2H_3 + CH + 62\ Cal/g \uparrow}$$

Dicalcium silicate (Belite) + Water → Calcium silicate hydrate + Calcium hydroxide +heat

Dicalcium silicate also affects the strength of concrete through its hydration. Dicalcium silicate reacts with water in a similar manner compared to tricalcium silicate, but much more slowly and contributes later strength. The heat released is less than that by the hydration of tricalcium silicate because the dicalcium silicate is much less reactive. The products from the hydration of dicalcium silicate are the same as those for tricalcium silicate:

iii. Hydration of Tricalcium Aluminate (Celite) :

It contributes to strength development in the first few days because it is the first compound to hydrate. It turns out higher heat of hydration and contributes to faster gain in strength. But it results in poor sulfate resitance and increases the volumetric shrinkage upon drying. Cements with low Tricalcium Aluminate contents usually generate less heat, develop higher strengths and show greater resistance to sulfate attacks. It has high heat generation and reactive with soils and water containing moderate to high sulfate concentrations so it’s least desirable. Ettringite consists of long crystals that are only stable in a solution with gypsum. The compound does not contribute to the strength of the cement glue.

$$\mathbf{C_3A + 3CSH_2 + 13H \rightarrow C_6AS_3H_{32} + 207\ Cal/g \uparrow}$$

Tricalcium Aluminate (Celite) + Gypsum + water → Ettringite + Heat

$$\mathbf{2C_3A + 3\ C_6AS_3H_{32} + 22H \rightarrow 3C_4ASH_{18}}$$

Tricalcium Aluminate + Ettringite + water → Monosulphate Aluminate Hydrate

Once all the gypsum is used up, the ettringite becomes unstable and reacts with any remaining tricalcium aluminate to form monosulfate aluminate hydrate crystals. The monosulfate crystals are only stable in a sulfate deficient solution. In the presence of sulfates, the crystals resort back into ettringite, whose crystals are two-and-a-half times the size of the monosulfate. It is this increase in size that causes cracking when cement is subjected to sulfate attack.

iv. Hydration of Ferrite (Tetra Calcium AluminoFerrite):

It assists in the manufacture of Portland Cement by allowing lower clinkering temperature. It also act as a filler contributes very little strength of concrete eventhough it hydrates very rapidly. It is also responsible for grey colour of Ordinary Portland Cement.

The ferrite undergoes two progressive reactions with the gypsum:

a. in the first of the reactions, the ettringite reacts with the gypsum and water to form ettringite, lime and alumina hydroxides

$$\mathbf{C_4AF + 3CSH_2 + 3H \rightarrow C_6(A,F)S_3H_{32} + (A,F)H_3 + CH}$$

Ferrite (Tetra Calcium AluminoFerrite) + gypsum + water → Ettringite + Ferric Aluminium Hydroxide + lime.

b. the ferrite further reacts with the ettringite formed above to produce garnets which simply occupy the space and do not contribute any strength to the cement paste.

$$\mathbf{C_4AF + C_6(A,F)S_3H_{32} + 2CH + 23H \rightarrow 3C_4(A,F)SH_{18} + (A,F)H_3}$$

Ferrite (Tetra Calcium AluminoFerrite) + Ettringite + lime + water → Garnets + Ferric Aluminium Hydroxide

Qualities of Water in concreting

The purposes of water in concrete are:

1. To wet the surface of aggregates to develop adhesion because the cement pastes adheres quickly and satisfactory to the wet surface of the aggregates than to a dry surface.
2. To prepare a plastic mixture of the various ingredients and to impart workability to concrete to facilitate placing in the desired position and
3. Water is also needed for the hydration of the cementing materials to set and harden during the period of curing.

The quantity of water in the mix plays a vital role on the strength of the concrete. Some water which have adverse effect on hardened concrete. Sometimes may not be harmless or even beneficial during mixing. So clear distinction should be made between the effect on hardened concrete and the quality of mixing water.

Water used for mixing and curing shall be clean and free from injurious quantities of alkalies, acids, oils , salts, sugar, organic materials, vegetable growth or other substance that may be deleterious to bricks, stone, concrete or steel.

Potable water is generally considered satisfactory for mixing.

Sea water shall not be used for mixing or curing.

Maximum permissible limits of solids when tested in accordance with IS 456 shall be as under:

Types of solids	Limits
Organic solids	200 mg/liter
Inorganic solids	3000 mg/liter
Sulphates	500 mg/liter
Chlorides	2000 mg/liter for concrete not containing embedded steel, and 500 mg/liter for reinforced concrete work
Suspended matter pH value	2000 mg/liter > 6

SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

UNIT – II – ADVANCED CONCRETE TECHNOLOGY– SCIA7001

UNIT II

PROPERTIES OF CONCRETE

Fresh concrete – Workability – Factors affecting workability – Measurement of workability – Segregation – Bleeding –Concrete manufacturing – Convention – Ready mix and Advantage of Ready mix – Finishing. Compaction – Curing – Strength of concrete – Elasticity – Creep – Shrinkage – Durability of concrete – Factors affecting strength of concrete and Durability of concrete – Cracks in concrete – Chemical attacks carbonation.

Fresh concrete

Fresh concrete: It is the concrete phase from time of mixing to end of time concrete surface finished in its final location in the structure

Concrete Operations: They comprise batching, mixing, transporting, placing, compacting, surface finishing. Then curing of in-placed concrete starts 6-10 hours after casting (placing) and during first few days of hardening is important it is known that fresh state properties enormously affect hardened state properties due to the following reasons:

• The potential strength and durability of concrete of a given mix proportion is very dependent on the degree of its compaction.

• The first 48 hours are very important for the performance of the concrete structure.

• It controls the long-term behavior, influence f'c (ultimate strength), Fc' (elastic modulus), creep, and durability.

Concrete workability is the relative ease with which a fresh mix can be handled, placed, compacted, and finished without segregation or separation of the individual ingredients. Fresh concrete has good workability if it can be formed, compacted, and finished to its final shape and texture with minimal effort and without segregation of the ingredients. Concrete with poor workability does not flow smoothly into forms or properly envelop reinforcing steel and embedded items, and it is difficult to compact and finish.

Factors which affect workability of concrete are:

i. Cement content of concrete

ii. Water content of concrete

iii. Mix proportions of concrete

iv. Size of aggregates

v. Shape of aggregates

vi. Grading of aggregates

vii. Surface texture of aggregates

viii. Use of admixtures in concrete

ix. Use of supplementary cementitious materials

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

Cement Content of Concrete:

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

Type and Composition of Cement:

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

Water / Cement Ratio or Water Content of Concrete:

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

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

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

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

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

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

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

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

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

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

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

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

The **use of steel or synthetic fibers in concrete** reduces the workability of concrete as it makes the movement of aggregates harder by reducing the lubricating effect of cement paste.
The workability of concrete is reduced and increased based on the quantity of **silica fume**. The use of silica fume in concrete can improves workability when used at low replacement rates, but can reduce workability when added at higher replacement rates. Silica fume are used as pumping aid for concrete when used as 2 to 3% by mass of cement.

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

METHODS FOR WORKABILITY MEASUREMENT

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

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

1. SLUMP TEST

SUITABILITY

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

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

Fig.Slump-Apparatus

PROCEDURE

The test is performed in the following steps:

1. Place the slump mould on a smooth flat and non-absorbent surface.
2. Mix the dry ingredients of the concrete thoroughly till a uniform colour is obtained and then add the required quantity of water in it.
3. Place the mixed concrete in the mould to about one-fourth of its height.
4. Compact the concrete 25 times with the help of a tamping rod uniformly all over the area.
5. Place the mixed concrete in the mould to about half of its height and compact it again.

6. Similarly, place the concrete upto its three-fourth height and then up to its top. Compact each layer 25 times with the help of tamping rod uniformly. For the second and subsequent layers, the tamping rod should penetrate into underlying layer.
7. Strike off the top surface of mould with a trowel or tamping rod so that the mould is filled to its top.
8. Remove the mould immediately, ensuring its movement in vertical direction.
9. When the settlement of concrete stops, measure the subsidence of the concrete in millimeters which is the required *slump* of the concrete.

RECOMMENDED SLUMP VALUES FOR VARIOUS CONCRETE WORKS

Type of Construction	**Recommend slump in mm**	
	Minimum	**Maximum**
Pavements	25	50
Mass concrete structure	25	50
Unreinforced footings	25	75
Caissons and bridge decks	25	75
Reinforced foundation, footings and walls	50	100
Reinforced slabs and beams	30	125
Columns	75	125

LIMITATIONS OF SLUMP TEST

Following are the limitations

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

2. COMPACTION FACTOR TEST

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

SUITABILITY

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

PROCEDURE

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

Compaction-Factor-Test-Apparatus

The test is performed in the following steps:

1. Clean and dry the internal surface of the mould.
2. With the help of hand scoop, place the concrete in upper hopper A.
3. Open the trap door of hopper in order to facilitate the falling of the concrete into lower hopper B. the concrete sticking to the sides of the hopper A, should be pushed downward with the help of a steel rod.
4. Open the trap door of the hopper B and allow the concrete to fall into cylinder C.
5. Remove the surplus concrete from the top of the cylinder with the help of a trowel. Wipe and clean the outside surface of the cylinder.
6. Weigh the cylinder with partially compacted concrete nearest to 10 g.

7. Fill in the cylinder with fresh concrete in layers not exceeding 5 cm in thickness and compact each layer till 100 percent compaction is achievd.
8. Wipe off and clean the outside surface of the cylinder and weigh the cylinder with fully compacted concrete nearest to 10 g.
9. Calculate the value of compaction factor using the following formula.

Compaction factor = $\frac{\text{weight of partially compacted concrete}}{\text{weight of fully compacted concrete}}$

RECOMMENDED VALUES OF WORKABILITY FOR VARIOUS PLACING CONDITIONS

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

ADVANTAGES OF COMPACTION FACTOR TEST

Following are the advantages:

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

3. VEE-BEE CONSISTOMETER TEST

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

Fig. Vee-Bee-Consistometer

SUITABILITY

This method is suitable for dry concrete having very low workability

PROCEDURE
The test is performed as given described below

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

COMPARISON OF WORKABILITY MEASUREMENTS BY VARIOUS METHODS

Workability Description	Slump in mm	Vee-bee Time in Seconds	Compacting Factor
Extremely dry	–	32 – 18	
Very stiff	–	18 – 10	0.70
Stiff	0 – 25	10 – 5	0.75
Stiff plastic	25 – 50	5 – 3	0.85
Plastic	75 – 100	3 – 0	0.90
Flowing	150 – 175	–	0.95

Segregation of concrete is separation of ingredients of concrete from each other. In good concrete all concrete aggregates are evenly coated with sand and cement paste and forms a homogeneous mass.
During handling, transporting and placing, due to jerks and vibrations the paste of cement and sands gets separated from coarse aggregate. If concrete segregates during transit it should be remixed properly before depositing. However a concrete where initial setting time is over, should not be used.

Causes of Segregation of Concrete:
1) Use of high water-cement ratio in concrete. This general happens in case of concrete mixed at site by unskilled workers.

2) Excessive vibration of concrete with mechanical needle vibrators makes heavier particles settle at bottom and lighter cement sand paste comes on top.

3) When concreting is done from height in case of underground foundations and rafts, which causes concrete to segregate.

Prevention of Segregation of Concrete:
Wherever depth of concreting is more than 1.5 meters it should be placed through temporary inclined chutes. The angle of inclination may be kept between 1:3 and 1:2 so that concrete from top of chutes travels smoothly to bottom, use of small quantity of free water from top at intervals helps in lubricating the path of flow of concrete to bottom smoothly. The delivery end of chute should be as close as possible to the point of deposit.

Segregation in deep foundations and rafts of thickness more than 1 meter, there is every possibility of presence of segregated concrete near bottom or in center if proper supervision is not there. Such segregation can be detected by advanced method of testing like ultrasonic testing. In case of doubt random ultrasonic testing should be conducted and if it is present, designer's opinion should be taken. This type of segregation can be rectified by pressure grounding with special chemical compounds.

After any defect rectified by pressure grouting core test has to be performed to ensure that the strength of concrete has reached to the desired level.

Concrete bleeding is defined as the appearance of water on the surface of concrete after it has consolidated but before it is set. This is a type of segregation where water appears at the concrete surface after placing and compacting, but before it is set. Water may also form a film under aggregate and reinforcing bar. Some bleeding is useful for finishing operations and to reduce plastic shrinkage cracking.
Problems due to Concrete Bleeding

Concrete bleeding can cause problems including the followings.

- It can delay in finishing.
- Bleeding of concrete can cause high water-cement ratio at the top.
- It will result in poor bond between two layers.
- It can result in poor pump ability.

Concrete Bleeding Causes

Bleeding of concrete occurs due to the causes stated below.

- The lack of fines,
- Too much water content in the mix.

Bleeding Remedies

Remedies for bleeding of concrete are as follows.

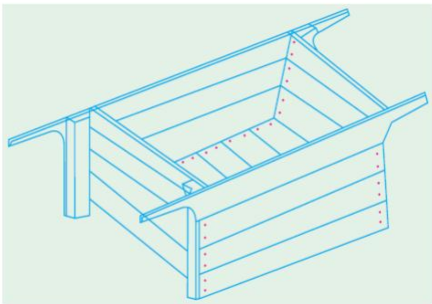
- More fines,
- Adjust grading,
- Entrained air,
- Reduce water content.

Manufacture of Concrete:

It is interesting to note that the ingredients of good concrete and bad concrete are the same. If meticulous care is not exercised, and good rules are not observed, the resultant concrete is going to be of bad quality. With the same material if intense care is taken to exercise control at every stage, it will result in good concrete. The various stages of manufacture of concrete are: (a) Batching (b) Mixing (c) Transporting (d) Placing (e) Compacting (f) Curing (g) Finishing.

Volume Batching:

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



Weigh Batching:

- Weigh batching is the correct method of measuring the materials.
- Use of weight system in batching, facilitates accuracy, flexibility and simplicity.
- Large weigh batching plants have automatic weighing equipment.
- On large work sites, the weigh bucket type of weighing equipment's are used.

Mixing: Hand mixing

- Hand mixing is practiced for small scale unimportant concrete works.
- As the mixing cannot be thorough and efficient, it is desirable to add 10 per cent more cement to cater for the inferior concrete produced by this method.
- Hand mixing should be done over an impervious concrete or brick floor of sufficiently large size to take one bag of cement.
- Spread out the measured quantity of coarse aggregate and fine aggregate in alternate layers.

- ✓ Pour the cement on the top of it, and mix them dry by shovel, turning the mixture over and over again until uniformity of colour is achieved.
- ✓ Water is taken in a water-can fitted with a rose-head and sprinkled over the mixture and simultaneously turned over.
- ✓ This operation is continued till such time a good uniform, homogeneous concrete is obtained.

Mixing: Machine Mixing

- Mixing of concrete is almost invariably carried out by machine, for reinforced concrete work and for medium or large scale mass concrete work.
- Machine mixing is not only efficient, but also economical, when the quantity of concrete to be produced is large.
- They can be classified as batch-mixers and continuous mixers.
- Batch mixers produce concrete, batch by batch with time interval, whereas continuous mixers produce concrete continuously without stoppage till such time the plant is working.

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

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

The following are the standardized sizes of three types:
a. Tilting: 85 T, 100 T, 140 T, 200 T
b. Non-Tilting: 200 NT, 280 NT, 375 NT, 500 NT, 1000 NT
c. Reversing: 200 R, 280 R, 375 R, 500 R and 1000 R

Nominal mix design

In the past the specifications for concrete prescribed the proportions of cement, fine and coarse aggregates. These mixes of fixed cement-aggregate ratio which ensures adequate strength are termed nominal mixes. These offer simplicity and under normal circumstances, have a margin of strength above that specified. However, due to the variability of mix ingredients the nominal concrete for a given workability varies widely in strength.

The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under- or over-rich mixes. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed standard mixes. IS 456-2000 has designated the concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter M refers to the mix and the number to the specified 28 day cube strength of mix in N/mm2 M10, M15, M20 and M25 correspond approximately to the mix proportions (1:3:6), (1:2:4), (1:1.5:3) and (1:1:2) respectively.

Ready Mix concrete

- Ready Mix Concrete (RMC) is a specialized material in which the cement aggregates and other ingredients are weigh-batched at a plant in a central mixer or truck mixer, before delivery to the construction site in a condition ready for placing by the builder.
- Thus, `fresh' concrete is manufactured in a plant away from the construction site and transported within the requisite journey time.
- The RMC supplier provides two services, firstly one of processing the materials for making fresh concrete and secondly, of transporting a product within a short time.

MIXING PROCESS:

- Thorough mixing of the materials is essential for the production of uniform concrete. The mixing should ensure that the mass becomes homogeneous, uniform in color and consistency. There are three methods adopted for mixing Ready Mix Concrete.
- Following are the three types of mixing process of RMC
  1. Transit Mixed (or "truck-mixed") Concrete
  2. Shrink Mixed Concrete
  3. Central Mixed Concrete

1. TRANSIT MIXING:-

It is also called dry batched concrete because all the basic ingredients including water are charged directly into the truck mixer. The mixer drum is revolved fast at charging speed during the loading of the material and after that it continues rotating at a normal agitating speed. In this type of ready mix concrete, also three types of variations are possible as given below:

i) Concrete mixed at job site:

While being transported towards the destination, the drum is revolved at a slow or agitating speed of 2 rpm, but after reaching the site just before discharging the material, it is revolved at maximum speed of 12 to 15 rpm for nearly 70 to 100 revolution for ensuring homogeneous mixing.

ii) Concrete mixed in transit

The drum speed is kept medium during the transit time, i.e. approximately 8 rpm for about 70 revolutions. After 70 revolutions, it is slowed down to agitating speed of 2 rpm till discharging the concrete.

iii) Concrete mixed in the yard

The drum is turned at high-speed of 12 to 15 rpm for about 50 revolutions in the yard itself. The concrete is then agitated slowly during transit time.

2. Shrink mixed concrete:

The concrete is partially mixed in the plant mixer and then balance mixing is done in the truck mounted drum mixer during transit time. The amount of mixing in transit mixer depends upon the extent of mixing done in the central mixing plant. Tests should be conducted to establish the requirement of mixing the drum mixer.

3. Central mixed concrete:

It is also called central batching plant where the concrete is thoroughly mixed before loading into the truck mixer. Sometimes the plant is also referred as wet-batch or pre-mix plants. While transporting the concrete, the truck mixer acts as agitator only. Sometimes, when workability requirement is low or the lead is less, non-agitating units or dump trucks can also be used.

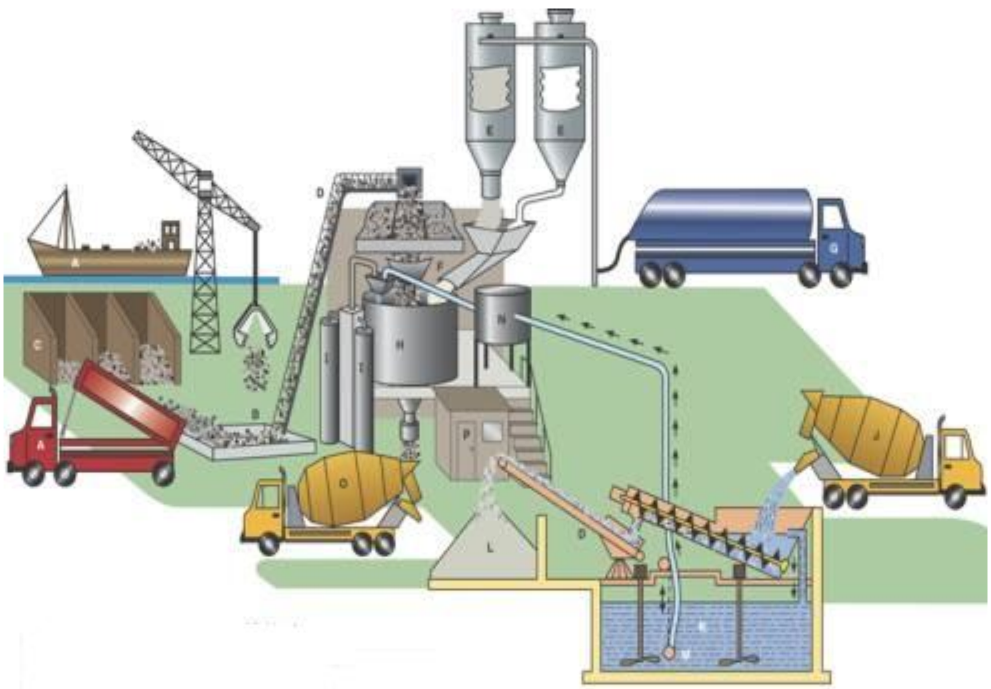


Fig. Ready mix batching plant

Advantages of Ready Mixed Concrete:

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

Disadvantages

- The materials are batched at a central plant, and the mixing begins at that plant, so the traveling time from the plant to site is critical over longer distances.
- Access roads, and site access have to be able to carry the weight of the truck and load concrete is approx 2.5 tonne.
- concrete's limited time span between mixing and going-off means that ready-mix should be placed within 2hours of batching at the plant

Finishing

Finishing is the operation of creating a concrete surface of a desired texture, smoothness and durability. The finishing can be functional and decorative.

Compaction

The concrete as a whole contain voids can be caused by inadequate compaction. Usually it being governed by the compaction equipments used, type of formworks, and density of the steelwork.

Strength of concrete

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

Tests can be made to ensure the properties of concrete correspond to specifications for the application. The density of concrete varies, but is around 2,400 kilograms per cubic metre. As a result, without compensating, concrete would almost always fail from tensile stresses – even when loaded in compression. The practical implication of this is that concrete elements subjected to tensile stresses must be reinforced with materials that are strong in tension.

Elasticity

The modulus of elasticity of concrete is a function of the modulus of elasticity of the aggregates and the cement matrix and their relative proportions. The modulus of elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develops. The elastic modulus of the hardened paste may be in the order of 10-30 GPa and aggregates about 45 to 85 GPa. The concrete composite is then in the range of 30 to 50 GPa.

Creep in concrete

Concrete creep is defined as: deformation of structure under sustained load. Basically, long term pressure or stress on concrete can make it change shape. This deformation usuall occurs in the direction the force is being applied. Creep does not necessarily cause concrete to fail or break apart. Creep is factored in when concrete structures are designed.

Factors Affecting Creep:

1. Aggregate
2. Mix Proportions
3. Age of concrete

1. Influence of Aggregate

Aggregate undergoes very little creep. It is really the paste which is responsible for the creep. However, the aggregate influences the creep of concrete through a restraining effect on the magnitude of creep. The paste which is creeping under load is restrained by aggregate which do not creep. The stronger the aggregate the more is the restraining effect and hence the less is the magnitude of creep. The modulus of elasticity of aggregate is one of the important factors influencing creep. It can be easily imagined that the higher the modulus of elasticity the less is the creep. Light weight aggregate shows substantially higher creep than normal weight aggregate.

2. Influence of Mix Proportions

The amount of paste content and its quality is one of the most important factors influencing creep. A poorer paste structure undergoes higher creep. Therefore, it can be said that creep increases with increase in water/cement ratio. In other words, it can also be said that creep is inversely proportional to the strength of concrete. Broadly speaking, all other factors which are affecting the water/cement ratio are also affecting the creep.

3. Influence of Age

Age at which a concrete member is loaded will have a predominant effect on the magnitude of creep. This can be easily understood from the fact that the quality of gel improves with time. Such gel creeps less, whereas a young gel under load being not so stronger creeps more. What is said above is not a very accurate statement because of the fact that the moisture content of the concrete being different at different age also influences the magnitude of creep.

Effects of Creep on Concrete and Reinforced Concrete:

In reinforced concrete beams, creep increases the deflection with time and may be a critical consideration in design. In eccentrically loaded columns, creep increases the deflection and can load to buckling. In case of statically indeterminate structures and column and beam junctions creep may relieve the stress concentration induced by shrinkage, temperatures changes or movement of support. Creep property of concrete will be useful in all concrete structures to reduce the internal stresses due to non-uniform load or restrained shrinkage.

In mass concrete structures such as dams, on account of differential temperature conditions at the interior and surface, creep is harmful and by itself may be a cause of cracking in the interior of dams. Therefore, all precautions and steps must be taken to see that increase in temperature does not take place in the interior of mass concrete structure. Loss of pre stress due to creep of concrete in pre stressed concrete structure.

Shrinkage in Concrete

change is one of the most detrimental properties of concrete, which affects the long-term strength and durability. To the practical engineer, the aspect of volume change in concrete is important from the point of view that it causes unsightly cracks in concrete. We have discussed elsewhere the effect of volume change due to thermal properties of aggregate and concrete, due to alkali/aggregate reaction, due to sulphate action etc. Presently we shall discuss the volume change on account of inherenet properties of concrete “shrinkage”. One of the most objectionable defects in concrete is the presence of cracks, particularly in floors and pavements. One of the important factors that contribute to the cracks in floors and pavements is that due to shrinkage. It is difficult to make concrete which does not shrink and crack. It is only a question of magnitude. The term shrinkage is loosely used to describe the various aspects of volume changes in concrete due to loss of moisture at different stages due to different reasons.

Types of Shrinkage in Concrete

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

(a) Plastic Shrinkage

(b) Drying Shrinkage

(c) Autogeneous Shrinkage

(d) Carbonation Shrinkage

a. Plastic Shrinkage

Shrinkage of this type manifests itself soon after the concrete is placed in the forms while the concrete is still in the plastic state. Loss of water by evaporation from the surface of concrete or by the absorption by aggregate or subgrade, is believed to be the reasons of plastic shrinkage. The loss of water results in the reduction of volume. The aggregate particles or the reinforcement comes in the way of subsidence due to which cracks may appear at the surface or internally around the aggregate or reinforcement.

In case of floors and pavements where the surface area exposed to drying is large as compared to depth, when this large surface is exposed to hot sun and drying wind, the surface of concrete dries very fast which results in plastic shrinkage. Sometimes even if theconcrete is not subjected to severe drying, but poorly made with a high water/cement ratio, large quantity of water bleeds and accumulates at the surface. When this water at the surface dries out, the surface concrete collapses causing cracks.

b. Drying Shrinkage

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

c. Autogeneous Shrinkage

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

d. Carbonation Shrinkage

Carbon dioxide present in the atmosphere reacts in the presence of water with hydrated cement. Calcium hydroxide [Ca(OH)2] gets converted to calcium carbonate and also some other cement compounds are decomposed. Such a complete decomposition of calcium compound in hydrated cement is chemically possible even at the low pressure of carbon dioxide in normal atmosphere. Carbonation penetrates beyond the exposed surface of concrete very slowly. The rate of penetration of carbon dioxide depends also on the moisture content of the concrete and the relative humidity of the ambient medium. Carbonation is accompanied by an increase in weight of the concrete and by shrinkage.
Carbonation shrinkage is probably caused by the dissolution of crystals of calcium hydroxide and deposition of calcium carbonate in its place. As the new product is less in volume than the product replaced, shrinkage takes place.

Curing

Curing of concrete is defined as the process of maintaining the moisture and temperature conditions of concrete for hydration reaction to normally so that concrete develops hardened properties over time. The main components which needs to be taken care are moisture, heat and time during curing process.

Curing of concrete is required for the following reasons:

- To prevent the concrete to dry out prematurely due to solar radiation and wind. This prevents plastic shrinkage of concrete.
- It helps to maintain the concrete temperature by allowing the hydration process. Hydration process requires water to carry on and releases heat.
- Curing helps the concrete to harden and bond with internal materials and reinforcement. This helps to prevent damage to bond between concrete and reinforcement due to vibration and impact.
- This helps development of impermeable, crack free and durable concrete.

Duration of curing

The **Indian Standard IS 456 – 2000** recommends that curing duration of concrete must be at least 7 days in case of ordinary Portland Cement, at least 10 days for concrete with mineral admixtures or blended cements are used. It also recommends that the curing duration should not be less than 10 days for concrete exposed to dry and hot weather conditions and 14 days for concrete with mineral admixtures or blended cement in hot and dry weather.

Elasticity

FACTORS AFFECTING CONCRETE STRENGTH

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

1. Quality of Raw Materials:

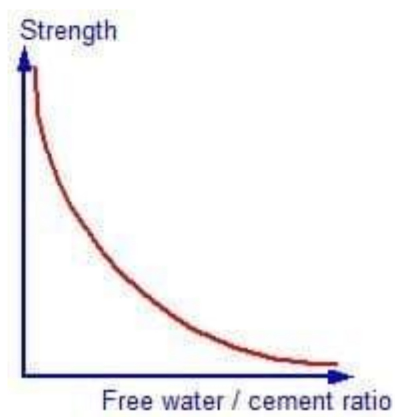
Cement: Provided the cement conforms with the appropriate standard and it has been stored correctly (i.e. in dry conditions), it should be suitable for use in concrete.

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

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

2. Water / Cement Ratio:

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



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

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

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

3. Coarse / fine aggregate ratio:

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

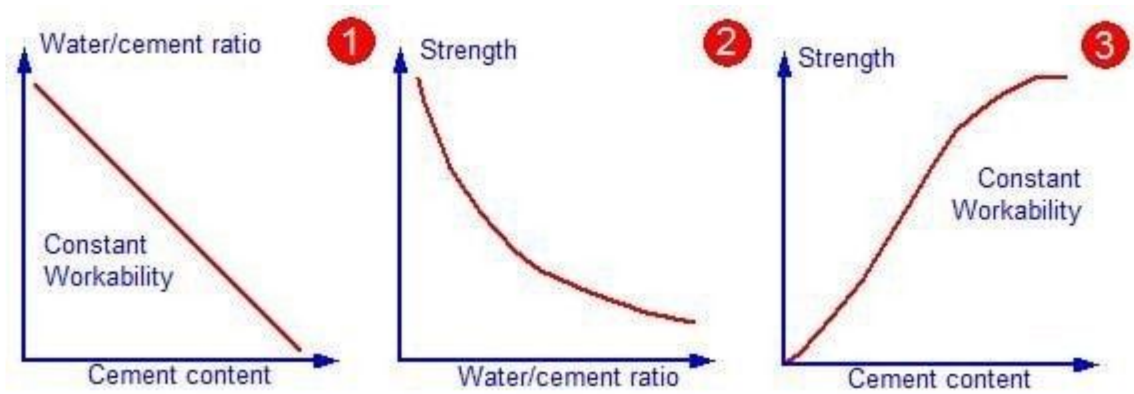
- If the proportion of fines is increased in relation to the coarse aggregate, the overall aggregate surface area will increase.
- If the surface area of the aggregate has increased, the water demand will also increase.
- Assuming the water demand has increased, the water cement ratio will increase.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

4. Aggregate / Cement Ratio:

Following points must be noted for aggregate cement ratio:

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

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



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

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

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

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

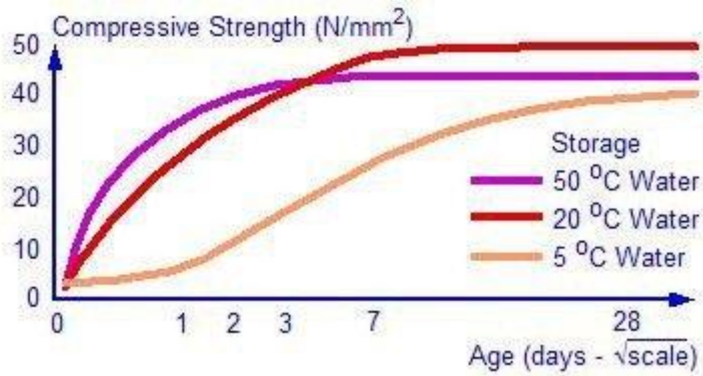
In theory, provided the concrete is not allowed to dry out, then it wil always be increasing albeit at an ever reducing rate. For convenience and for most practical applications, it is generally accepted that the majority of the strength has been achieved by 28 days.

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

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

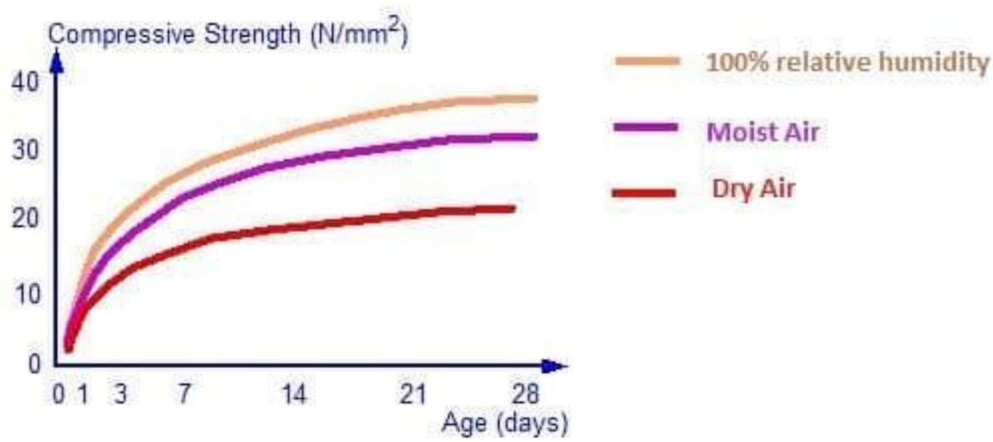
However, the final strength of the concrete kept at the higher temperature will be lower. This is because the physical form of the hardened cement paste is less well structured and more porous when hydration proceeds at faster rate.

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



8. Relative humidity:

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



9. Curing:

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

The ability of concrete to withstand the conditions for which it is designed without deterioration for a long period of years is known as durability.

Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties.

Durability is defined as the capability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desired engineering properties. It normally refers to the duration or life span of trouble-free performance. Different concretes require different degrees of durability depending on the exposure environment and properties desired. For example, concrete exposed to tidal seawater will have different requirements than indoor concrete.

Concrete will remain durable if:

- The cement paste structure is dense and of low permeability
- Under extreme condition, it has entrained air to resist freeze-thaw cycle.
- It is made with graded aggregate that are strong and inert
- The ingredients in the mix contain minimum impurities such as alkalis, Chlorides, sulphates and silt

Factors Affecting Durability of Concrete

Durability of Concrete depends upon the following factors:

i. **Cement content**

   Mix must be designed to ensure cohesion and prevent segregation and bleeding. If cement is reduced, then at fixed w/c ratio the workability will be reduced leading to inadequate compaction. However, if water is added to improve workability, water / cement ratio increases and resulting in highly permeable material.

ii. **Compaction**

   The concrete as a whole contain voids can be caused by inadequate compaction. Usually it is being governed by the compaction equipments used, type of formworks, and density of the steelwork

iii. **Curing**

   It is very important to permit proper strength development aid moisture retention and to ensure hydration process occur completely

iv. **Cover**

Thickness of concrete cover must follow the limits set in codes

v. **Permeability**

It is considered the most important factor for durability. It can be noticed that higher permeability is usually caused by higher porosity .Therefore, a proper curing, sufficient cement, proper compaction and suitable concrete cover could provide a low permeability concrete.

Causes for the Lack of Durability in Concrete

1. External Causes:

a. Extreme Weathering Conditions
b. Extreme Temperature
c. Extreme Humidity
d. Abrasion
e. Electrolytic Action
f. Attack by a natural or industrial liquids or gases

2. Internal Causes

a) Physical

- Volume change due to difference in thermal properties of aggregates and cement paste
- Frost Action

b) Chemical

- Alkali Aggregate Reactions

  i. Alkali Silica Reaction

  ii. Alkali Silicate Reaction

  iii. Alkali Carbonate Reaction

- Corrosion of Steel

Sulfate attack in concrete: Sulfate attack can be external or internal.

External: due to penetration of sulfates in solution, in groundwater for example, into the concrete from outside.

Internal: due to a soluble source being incorporated into the concrete at the time of mixing, gypsum in the aggregate, for example. External sulfate attack.This is the more common type and typically occurs where water containing dissolved sulfate penetrates the concrete. A fairly well-defined reaction front can often be seen in polished sections; ahead of the front the concrete is normal, or near normal. Behind the reaction front, the composition and microstructure of the concrete will have changed. These changes may vary in type or severity but commonly include:

• Extensive cracking
• Expansion
• Loss of bond between the cement paste and aggregate

• Alteration of paste composition, with mono sulfate phase converting to ettringite and, in later stages, gypsum formation. The necessary additional calcium is provided by the calcium hydroxide and calcium silicate hydrate in the cement paste. The effect of these changes is an overall loss of concrete strength.

Internal sulfate attack

Occurs where a source of sulfate is incorporated into the concrete when mixed. Examples include the use of sulfate-rich aggregate, excess of added gypsum in the cement or contamination. Proper screening and testing procedures should generally avoid internal sulfate attack.

Chlorides

Chloride Resistance : Chloride present in plain concrete that does not contain steel is generally not a durability concern. Concrete protects embedded steel from corrosion through its highly alkaline nature. The high pH environment in concrete (usually greater than 12.5) causes a passive and non corroding protective oxide film to form on steel. However, the presence of chloride ions from deicers or seawater can destroy or penetrate the film. Once the chloride corrosion threshold is reached, an electric cell is formed along the steel or between steel bars and the electrochemical process of carrions begins.

Corrosion:

Corrosion of reinforcing steel and other embedded metals is one of the leading causes of deterioration of concrete. When steel corrodes, the resulting rust occupies a greater volume than steel. The expansion creates tensile stresses in the concrete, which can eventually cause cracking and spalling.

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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

UNIT – III – ADVANCED CONCRETE TECHNOLOGY– SCIA7001

UNIT 3

MIX DESIGN

Concrete Mix Design

Introduction

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible, is termed the concrete mix design.

The proportioning of ingredient of concrete is governed by the required performance of concrete in 2 states, namely the plastic and the hardened states. If the plastic concrete is not workable, it cannot be properly placed and compacted. The property of workability, therefore, becomes of vital importance.

The compressive strength of hardened concrete which is generally considered to be an index of its other properties, depends upon many factors, e.g. quality and quantity of cement, water and aggregates; batching and mixing; placing, compaction and curing. The cost of concrete is made up of the cost of materials, plant and labour.

The variations in the cost of materials arise from the fact that the cement is several times costly than the aggregate, thus the aim is to produce as lean a mix as possible. From technical point of view the rich mixes may lead to high shrinkage and cracking in the structural concrete, and to evolution of high heat of hydration in mass concrete which may cause cracking.

The actual cost of concrete is related to the cost of materials required for producing a minimum mean strength called characteristic strength that is specified by the designer of the structure. This depends on the quality control measures, but there is no doubt that the quality control adds to the cost of concrete.

The extent of quality control is often an economic compromise, and depends on the size and type of job. The cost of labour depends on the workability of mix, e.g., a concrete mix of inadequate workability may result in a high cost of labour to obtain a degree of compaction with available equipment.

Requirements of concrete mix design

The requirements which form the basis of selection and proportioning of mix ingredients are :

a) The minimum compressive strength required from structural consideration

b) The adequate workability necessary for full compaction with the compacting equipment available.

c) Maximum water-cement ratio and/or maximum cement content to give adequate durability for the particular site conditions

d) Maximum cement content to avoid shrinkage cracking due to temperature cycle in mass concrete.

Types of Mixes

1. Nominal Mixes

In the past the specifications for concrete prescribed the proportions of cement, fine and coarse aggregates. These mixes of fixed cement-aggregate ratio which ensures adequate strength are termed nominal mixes. These offer simplicity and under normal circumstances, have a margin of strength above that specified. However, due to the variability of mix ingredients the nominal concrete for a given workability varies widely in strength.

2. Standard mixes

The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under- or over-rich mixes. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed standard mixes.

IS 456-2000 has designated the concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter M refers to the mix and the number to the specified 28 day cube strength of mix in N/mm^2. The mixes of grades M10, M15, M20 and M25 correspond approximately to the mix proportions (1:3:6), (1:2:4), (1:1.5:3) and (1:1:2) respectively.

3. Designed Mixes

In these mixes the performance of the concrete is specified by the designer but the mix proportions are determined by the producer of concrete, except that the minimum cement content can be laid down. This is most rational approach to the selection of mix proportions with specific materials in mind possessing more or less unique characteristics. The approach results in the production of concrete with the appropriate properties most economically. However, the designed mix does not serve as a guide since this does not guarantee the correct mix proportions for the prescribed performance.

For the concrete with undemanding performance nominal or standard mixes (prescribed in the codes by quantities of dry ingredients per cubic meter and by slump) may be used only for very small jobs, when the 28-day strength of concrete does not exceed 30 N/mm^2. No control testing is necessary reliance being placed on the masses of the ingredients.

<u>Factors affecting the choice of mix proportions</u>

The various factors affecting the mix design are:

1. <u>Compressive strength</u>

It is one of the most important properties of concrete and influences many other describable properties of the hardened concrete. The mean compressive strength required at a specific age, usually 28 days, determines the nominal water-cement ratio of the mix. The other factor affecting the strength of concrete at a given age and cured at a prescribed temperature is the degree of compaction. According to Abraham's law the strength of fully compacted concrete is inversely proportional to the water-cement ratio.

2. <u>Workability</u>

The degree of workability required depends on three factors. These are the size of the section to be concreted, the amount of reinforcement, and the method of compaction to be used. For the narrow and complicated section with numerous corners or inaccessible parts, the concrete must have a high workability so that full compaction can be achieved with a reasonable amount of effort. This also applies to the embedded steel sections. The desired workability depends on the compacting equipment available at the site.

3. <u>Durability</u>

The durability of concrete is its resistance to the aggressive environmental conditions. High strength concrete is generally more durable than low strength concrete. In the situations when the high strength is not necessary but the conditions of exposure are such that high durability is vital, the durability requirement will determine the water-cement ratio to be used.

4. <u>Maximum nominal size of aggregate</u>

In general, larger the maximum size of aggregate, smaller is the cement requirement for a particular water-cement ratio, because the workability of concrete increases with increase in maximum size of the aggregate. However, the compressive strength tends to increase with the decrease in size of aggregate.

IS 456:2000 and IS 1343:1980 recommend that the nominal size of the aggregate should be as large as possible.

5. <u>Grading and type of aggregate</u>

The grading of aggregate influences the mix proportions for a specified workability and water-cement ratio. Coarser the grading leaner will be mix which can be used. Very lean mix is not desirable since it does not contain enough finer material to make the concrete cohesive.

The type of aggregate influences strongly the aggregate-cement ratio for the desired workability and stipulated water cement ratio. An important feature of a satisfactory aggregate is the uniformity of the grading which can be achieved by mixing different size fractions.

6. <u>Quality Control</u>

The degree of control can be estimated statistically by the variations in test results. The variation in strength results from the variations in the properties of the mix ingredients and lack of control of accuracy in batching, mixing, placing, curing and testing. The lower the difference between the mean and minimum strengths of the mix lower will be the cement-content required. The factor controlling this difference is termed as quality control.

<u>Mix Proportion designations</u>

The common method of expressing the proportions of ingredients of a concrete mix is in the terms of parts or ratios of cement, fine and coarse aggregates. For e.g., a concrete mix of proportions 1:2:4 means that cement, fine and coarse aggregate are in the ratio 1:2:4 or the mix contains one part of cement, two parts of fine aggregate and four parts of coarse aggregate. The proportions are either by volume or by mass. The water-cement ratio is usually expressed in mass

<u>Factors to be considered for mix design</u>

1. The grade designation giving the characteristic strength requirement of concrete.
2. The type of cement influences the rate of development of compressive strength of concrete.
3. Maximum nominal size of aggregates to be used in concrete may be as large as possible within the limits prescribed by IS 456:2000.
4. The cement content is to be limited from shrinkage, cracking and creep.
5. The workability of concrete for satisfactory placing and compaction is related to the size and shape of section, quantity and spacing of reinforcement and technique used for transportation, placing and compaction.

<u>Methods of proportioning</u>

1. Arbitrary proportion
2. Fineness modulus method
3. Maximum density method
4. Surface area Method
5. Indian Road Congress, IRC 44 method
6. High strength concrete mix design
7. Mix design baed on flexural strength
8. Road Note.4 (Grading curve method)
9. ACI committee 211 method
10. DOE method
11. Mix design for pumpable concrete
12. Indian standard recommended method IS 10262-82

Indian standard recommended method IS 10262-82

Procedure

1. Determine the mean target strength f_t from the specified characteristic compressive strength at 28-day f_{ck} and the level of quality control.

$$f_t = f_{ck} + 1.65\ S$$

where S is the standard deviation obtained from the Table of approximate contents given after the design mix.

2. Obtain the water cement ratio for the desired mean target using the emperical relationship between compressive strength and water cement ratio so chosen is checked against the limiting water cement ratio. The water cement ratio so chosen is checked against the limiting water cement ratio for the requirements of durability given in table and adopts the lower of the two values.

3. Estimate the amount of entrapped air for maximum nominal size of the aggregate from the table.

4. Select the water content, for the required workability and maximum size of aggregates (for aggregates in saturated surface dry condition) from table.

5. Determine the percentage of fine aggregate in total aggregate by absolute volume from table for the concrete using crushed coarse aggregate.

6. Adjust the values of water content and percentage of sand as provided in the table for any difference in workability, water cement ratio, grading of fine aggregate and for rounded aggregate the values are given in table.

7. Calculate the cement content form the water-cement ratio and the final water content as arrived after adjustment. Check the cement against the minimum cement content from the requirements of the durability, and greater of the two values is adopted.

8. From the quantities of water and cement per unit volume of concrete and the percentage of sand already determined in steps 6 and 7 above, calculate the content of coarse and fine aggregates per unit volume of concrete from the following relations:

$$V = \left[W + \frac{C}{S_c} + \frac{1}{p}\frac{f_a}{S_{fa}}\right] \times \frac{1}{1000}$$

$$V = \left[W + \frac{C}{S_c} + \frac{1}{1-p}\frac{C_a}{S_{ca}}\right] \times \frac{1}{1000}$$

where V = absolute volume of concrete

= gross volume ($1m^3$) minus the volume of entrapped air

S_c = specific gravity of cement

W = Mass of water per cubic metre of concrete, kg

C = mass of cement per cubic metre of concrete, kg

p = ratio of fine aggregate to total aggregate by absolute volume

f_a, C_a = total masses of fine and coarse aggregates, per cubic metre of concrete, respectively, kg, and

S_{fa}, S_{ca} = specific gravities of saturated surface dry fine and coarse aggregates, respectively

9. Determine the concrete mix proportions for the first trial mix.

10. Prepare the concrete using the calculated proportions and cast three cubes of 150 mm size and test them wet after 28-days moist curing and check for the strength.

11. Prepare trial mixes with suitable adjustments till the final mix proportions are arrived at.

Evaluation of Statistical Quality Control of Concrete

1 Variation in strength of concrete

The strength of concrete produced in sites is varied between mixes and even in the same mix due to the following reasons:

Table 2.1—Principal sources of strength variation

Variations due to the properties of concrete	Variations due to testing methods
•Changes in *w/cm* caused by: -Poor control of water -Excessive variation of moisture in aggregate or variable aggregate moisture measurements -Retempering	•Improper sampling procedures
•Variations in water requirement caused by: -Changes in aggregate grading, absorption, particle shape -Changes in cementitious and admixture properties -Changes in air content -Delivery time and temperature changes	•Variations due to fabrication techniques: -Handling, storing, and curing of newly made cylinders -Poor quality, damaged, or distorted molds
•Variations in characteristics and proportions of ingredients: -Aggregates -Cementitious materials, including pozzolans -Admixtures	•Changes in curing: -Temperature variation -Variable moisture control -Delays in bringing cylinders to the laboratory -Delays in beginning standard curing
•Variations in mixing, transporting, placing, and consolidation	•Poor testing procedures: -Specimen preparation -Test procedure -Uncalibrated testing equipment
•Variations in concrete temperature and curing	

2- Analysis of Strength Data

2. 1 Definitions

- ✓ **Concrete sample**—a portion of concrete, taken at one time, from a single batch or single truckload of concrete.
- ✓ **Single cylinder (cube) strength or individual strength**—the strength of a single Cylinder; a single cylinder strength does not constitute a test result.
- ✓ **Companion cylinders**—cylinders made from the same sample of concrete.
- ✓ **Strength test or strength test result**—the average of two or more single-cylinder strengths of specimens made from the same concrete sample (companion cylinders) and tested at the same age.
- ✓ **Range or within-test range**—the difference between the maximum and minimum strengths of individual concrete specimens comprising one strength test result.
- ✓ **Test record—**a collection of strength test results of a single concrete mixture.

2. 2 Statistical Functions

A sufficient number of tests are needed to indicate accurately the variation in the concrete produced and to permit appropriate statistical procedures for interpreting the test results. Statistical procedures provide a sound basis for determining from such results the potential quality and strength of the concrete and for expressing results in the most useful form.

A strength test result is defined as the average strength of all specimens of the same age, fabricated from a sample taken from a single batch of concrete. A strength test cannot be based on only one cylinder; a minimum of two cylinders is required for each test.

Concrete tests for strength are typically treated as if they fall into a distribution pattern similar to the normal frequency distribution curve illustrated in Fig. 3.1.

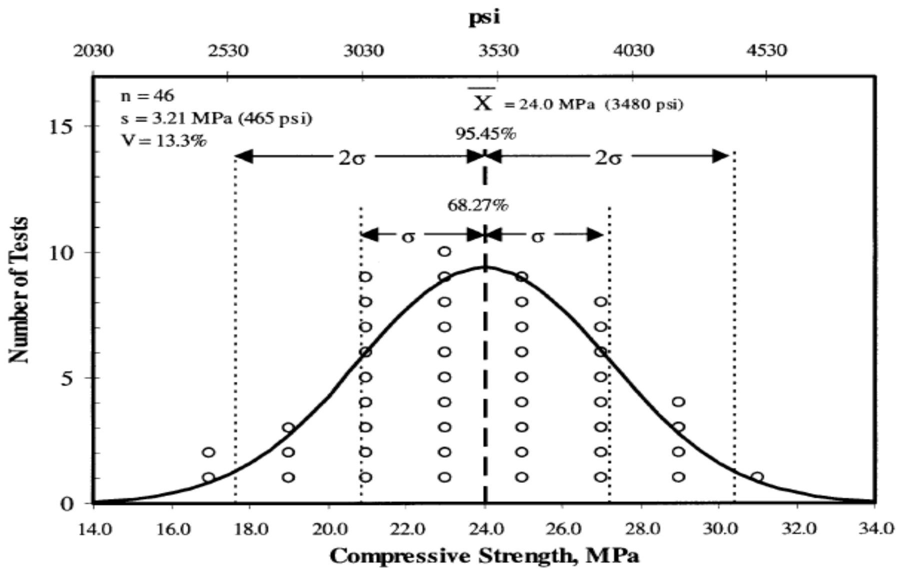

Fig. 3.1—Frequency distribution of strength data and corresponding assumed normal distribution.

When there is good control, the strength test values will tend to cluster near to the average value, that is, the histogram of test results is tall and narrow. As variation instrength results increases, the spread in the data increases and the normal distribution curve becomes lower and wider (Fig. 3.2).

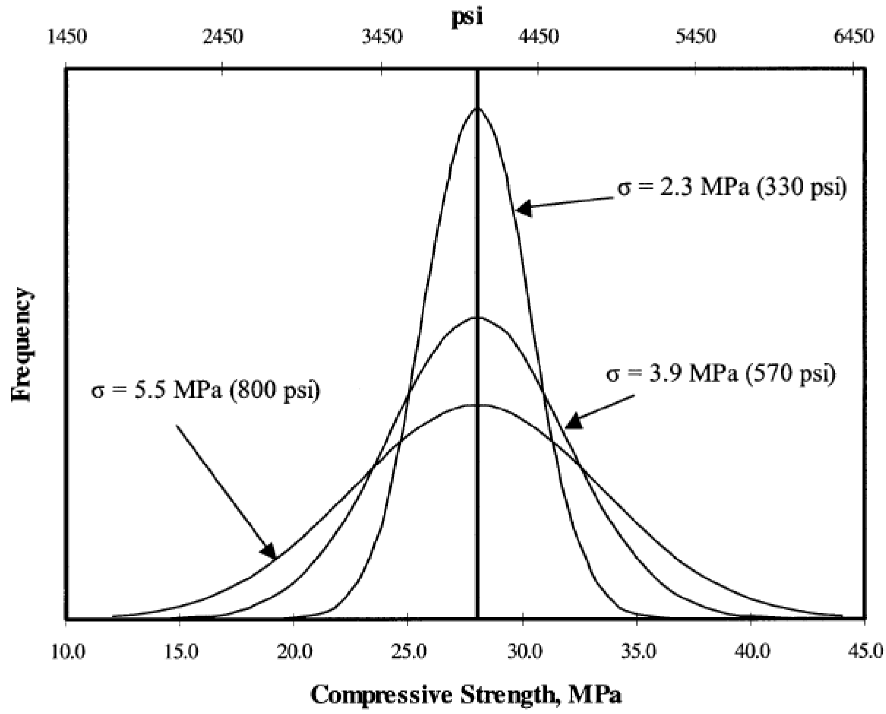

Fig. 3.2—Normal frequency curves for three different distributions with the same mean but different variability.

The normal distribution can be fully defined mathematically by two statistical parameters: the mean and standard deviation. These statistical parameters of the strength can be calculated as shown below:

- **Mean** , The average strength tests result is calculated using the following equation

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} = \frac{1}{n}\sum X_i = \frac{1}{n}(X_1 + X_2 + X_3 + \ldots + X_n) \quad (3\text{-}1)$$

where X_i is the i-th strength test result, the average of at least two cylinder strength tests. X_2 is the second strength test result in the record, ΣX_i is the sum of all strength test results and n is the number of tests in the record.

Standard deviations, the standard deviation is the most generally recognized measure of dispersion of the individual test data from their average.

$$s = \sqrt{\frac{n\sum_{i=1}^{n} X_i^2 - \left(\sum_{i=1}^{n} X_i\right)^2}{n(n-1)}} = \sqrt{\frac{\sum_{i=1}^{n} X_i^2 - n\overline{X}^2}{n-1}} \qquad (3\text{-}2b)$$

where s is the sample standard deviation, n is the number of strength test results in the record, $\overline{X}$ is the mean, or average, strength test result, and ΣX is the sum of the strength test results.

Coefficient of variation V - the sample standard deviation expressed as a percentage of the average strength is called the coefficient of variation

$$V = \frac{s}{\overline{X}} \times 100 \qquad (3\text{-}4)$$

where V is the coefficient of variation, s is the sample standard deviation, and $\overline{X}$ is the average strength test result.

The coefficient of variation is less affected by the magnitude of the strength level, and is therefore more useful than the standard deviation in comparing the degree of control for a wide range of compressive strengths. The coefficient of variation is typically used when

Coefficient of variation V - the sample standard deviation expressed as a percentage of the average strength is called the coefficient of variation

$$V = \frac{s}{\overline{X}} \times 100 \qquad (3\text{-}4)$$

where V is the coefficient of variation, s is the sample standard deviation, and $\overline{X}$ is the average strength test result.

The coefficient of variation is less affected by the magnitude of the strength level, and is therefore more useful than the standard deviation in comparing the degree of control for a wide range of compressive strengths. The coefficient of variation is typically used when

2- Analysis of Strength Data

be fully defined mathematically by two statistical parameters: the mean and standard deviation. These statistical parameters of the strength can be calculated as shown below:

- **Mean** , The average strength tests result is calculated using the following equation

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n} = \frac{1}{n}\sum X_i = \frac{1}{n}(X_1 + X_2 + X_3 + \ldots + X_n) \quad (3\text{-}1)$$

where X_i is the i-th strength test result, the average of at least two cylinder strength tests. X_2 is the second strength test result in the record, ΣX_i is the sum of all strength test results and n is the number of tests in the record.

- **Standard deviations,** the standard deviation is the most generally recognized measure of dispersion of the individual test data from their average.

$$s = \sqrt{\frac{n\sum_{i=1}^{n} X_i^2 - \left(\sum_{i=1}^{n} X_i\right)^2}{n(n-1)}} = \sqrt{\frac{\sum_{i=1}^{n} X_i^2 - n\overline{X}^2}{n-1}} \quad (3\text{-}2b)$$

where s is the sample standard deviation, n is the number of strength test results in the record, $\overline{X}$ is the mean, or average, strength test result, and ΣX is the sum of the strength test results.

- **Coefficient of variation V -** the sample standard deviation expressed as a percentage of the average strength is called the coefficient of variation

The coefficient of variation is less affected by the magnitude of the strength level, and is therefore more useful than the standard deviation in comparing the degree of control for a wide range of compressive strengths. The coefficient of variation is typically used when

2.3 Strength variations

Variations in strength test results can be traced to two different sources:

1. Variations in testing methods; and
2. Variations in the properties or proportions of the constituent materials in the concrete mixture, variations in the production, delivery or handling procedures, and variations in climatic conditions.

It is possible to compute the variations attributable to each source using analysis of variance (ANOVA) techniques or with simpler techniques.

1- ***Within-test variation***—**Variability due to testing** is estimated by the within-test variation based on differences in strengths of companion (replicate) cylinders comprising a strength test result. The within-test variation is affected by variations in sampling, molding, consolidating, transporting, curing, capping, and testing specimens. A single strength test result of a concrete mixture, however, does not provide sufficient data for statistical analysis. As with any statistical estimator, the confidence in the estimate is a function of the number of test results.

$$s_1 = \frac{1}{d_2}\overline{R} \qquad (3\text{-}5)$$

$$V_1 = \frac{s_1}{\overline{\overline{X}}} \times 100 \qquad (3\text{-}6)$$

Table 3.1—Factors for computing within-test standard deviation from range

No. of specimens	d_2
2	1.128
3	1.693
4	2.059

Note: From Table 49, *ASTM Manual on Presentation of Data and Control Chart Analysis,* MNL 7.

2-Batch-to-Batch variation - These variations reflect differences in strength from batch to batch, which can be attributed to variations in:

(a) Characteristics and properties of the ingredients; and

(b) Batching, mixing, and sampling.

Batch-to-batch variation can be estimated from strength test results of a concrete mixture if each test result represents a separate batch of concrete.

The ***overall variation s*** has two component variations, the within-test s_1 , and batch-to-batch s_2 variations. The sample variance—the squareof the sample standard deviation—is the sum of the sample within-test and sample batch-to-batch variances

$$s^2 = s_1^2 + s_2^2 \qquad (3\text{-}7)$$

From which the batch – to – batch standard deviation can be computed as

$$s_2 = \sqrt{s^2 - s_1^2} \qquad (3\text{-}8)$$

The within-test sample standard deviation estimates the variation attributable to sampling, specimen preparation, curing and testing, assuming proper testing methods are used. The batch-to-batch sample standard deviation estimates the variations attributable to constituent material suppliers, and the concrete producer.

2.4 Interpretation of statistical parameters

Once the statistical parameters have been computed, and with the assumption or verification that the results follow a normal frequency distribution curve, additional analysis of the test results is possible. Figure 3.3 indicates an approximate division of the area under the normal frequency distribution curve. For example, approximately 68% of the area (equivalent to 68% of the results) lies within ±1σof the average, and 95% lies within ±2σ.

This permits an estimate of the portion of the test results expected to fall within given multiples z of σ of the average or of any other specific value.

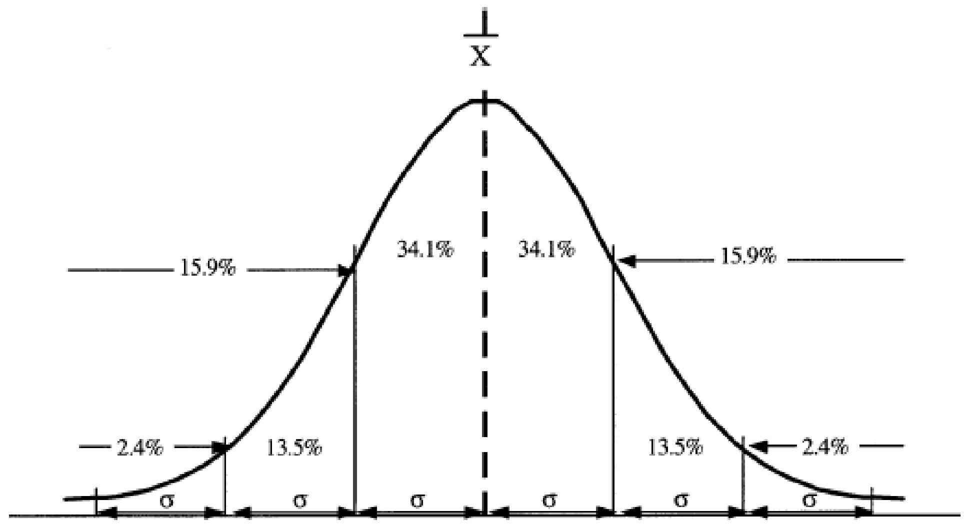

Fig. 3.3—Approximate distribution of area under normal frequency distribution curve.

Table 3.4 was adapted from the normal cumulative distribution (the normal probability integral) and shows the probability of a fraction of tests falling below fc′in terms of the average strength of the population of test results when the population average strength μ equals fc′ + zσ.

Table 3.4—Expected percentages of individual tests lower than f_c' *

Average strength μ	Expected percentage of low tests	Average strength μ	Expected percentage of low tests
$f_c' + 0.10\sigma$	46.0	$f_c' + 1.6\sigma$	5.5
$f_c' + 0.20\sigma$	42.1	$f_c' + 1.7\sigma$	4.5
$f_c' + 0.30\sigma$	38.2	$f_c' + 1.8\sigma$	3.6
$f_c' + 0.40\sigma$	34.5	$f_c' + 1.9\sigma$	2.9
$f_c' + 0.50\sigma$	30.9	$f_c' + 2.0\sigma$	2.3
$f_c' + 0.60\sigma$	27.4	$f_c' + 2.1\sigma$	1.8
$f_c' + 0.70\sigma$	24.2	$f_c' + 2.2\sigma$	1.4
$f_c' + 0.80\sigma$	21.2	$f_c' + 2.3\sigma$	1.1
$f_c' + 0.90\sigma$	18.4	$f_c' + 2.4\sigma$	0.8
$f_c' + 1.00\sigma$	15.9	$f_c' + 2.5\sigma$	0.6
$f_c' + 1.10\sigma$	13.6	$f_c' + 2.6\sigma$	0.45
$f_c' + 1.20\sigma$	11.5	$f_c' + 2.7\sigma$	0.35
$f_c' + 1.30\sigma$	9.7	$f_c' + 2.8\sigma$	0.25
$f_c' + 1.40\sigma$	8.1	$f_c' + 2.9\sigma$	0.19
$f_c' + 1.50\sigma$	6.7	$f_c' + 3.0\sigma$	0.13

*where μ exceeds f_c' by amount shown.

2.4 Standards of Control

One of the primary purposes of statistical evaluation of concrete data is to identify sources of variability. This knowledge can then be used to help determine appropriate steps to maintain the desired level of control. Several different techniques can be used to detect variations in concrete production, materials processing and handling, and contractor and testing agency operations. One simple approach is to compare **overall variability** and **within-test variability**, using eitherstandard deviation or coefficient of variation, as appropriate, with previous performance.

Table 3.2 gives the standards of control whichare appropriate for concrete having specified strengths up to 35 MPa (5000 psi), whereas Table 3.3 gives the appropriate standards of control for specified strengths over 35 MPa (5000 psi). These standards of control were adopted based on examination and analysis of compressive strength data by ACI Committee 214 and ACI Committee 363. The strength tests were conducted using 150 x 300 mm (6 x12 in.) cylinders.

Table 3.2—Standards of concrete control*

Overall variation					
Class of operation	Standard deviation for different control standards, MPa (psi)				
	Excellent	Very good	Good	Fair	Poor
General construction testing	Below 2.8 (below 400)	2.8 to 3.4 (400 to 500)	3.4 to 4.1 (500 to 600)	4.1 to 4.8 (600 to 700)	Above 4.8 (above 700)
Laboratory trial batches	Below 1.4 (below 200)	1.4 to 1.7 (200 to 250)	1.7 to 2.1 (250 to 300)	2.1 to 2.4 (300 to 350)	Above 2.4 (above 350)
Within-test variation					
Class of operation	Coefficient of variation for different control standards, %				
	Excellent	Very good	Good	Fair	Poor
Field control testing	Below 3.0	3.0 to 4.0	4.0 to 5.0	5.0 to 6.0	Above 6.0
Laboratory trial batches	Below 2.0	2.0 to 3.0	3.0 to 4.0	4.0 to 5.0	Above 5.0

*$f_c' \leq 34.5$ MPa (5000 psi).

Table 3.3—Standards of concrete control*

Overall variation					
Class of operation	Coefficient of variation for different control standards,%				
	Excellent	Very good	Good	Fair	Poor
General construction testing	Below 7.0	7.0 to 9.0	9.0 to 11.0	11.0 to 14.0	Above 14.0
Laboratory trial batches	Below 3.5	3.5 to 4.5	4.5 to 5.5	5.5 to 7.0	Above 7.0
Within-test variation					
Class of operation	Coefficient of variation for different control standards, %				
	Excellent	Very good	Good	Fair	Poor
Field control testing	Below 3.0	3.0 to 4.0	4.0 to 5.0	5.0 to 6.0	Above 6.0
Laboratory trial batches	Below 2.0	2.0 to 3.0	3.0 to 4.0	4.0 to 5.0	Above 5.0

*$f_c' > 34.5$ MPa (5000 psi).

Criteria

The strength of concrete in a structure and the strength of test cylinders cast from a sample of that concrete are not necessarily the same. The strength of the cylinders obtained from that sample of concrete and used for contractual acceptance are to be cured and tested under tightly controlled conditions. The strengths of these cylinders are generally the primary evidence of the quality of concrete used in the structure. The engineer specifies the desired strength, the testing frequency, and the permitted tolerance in compressive strength.

Any specified quantity, including strength, should also have a tolerance. It is impractical to specify an absolute minimum strength, because there is always the possibility of even lower strengths simply due to random variation, even when control is good. There will always be a certain probability of tests falling below fc′. ACI 318 and most other building codes and specifications establish tolerances for meeting the specified compressive strength acceptance criteria, analogous to the tolerances for other building materials.

To satisfy statistically based strength-performance requirements, the average strength of the concrete should be in excess of the specified compressive strength fc′. **The required average strength fcr′ which is the strength used in mixture proportioning**, depends on the expected variability of test results as measured by the coefficient of variation or standard deviation, and on the allowable proportion of tests below the appropriate, specified acceptance criteria.

3.1 Data used to establish the minimum required average strength

To establish the required average strength fcr′ (target strength), an estimate of the variability of the concrete to be supplied for construction is needed. The strength test record used to estimate the standard deviation or coefficient of variation should represent a group of at least 30 consecutive tests.

The requirement for 30 consecutive strength tests can be satisfied by using a test record of 30 consecutive batches of the same class of concrete or the statistical average of two test records totaling 30 or more tests. If the number of test results available is less than 30, a more conservative approach is needed. Test records with as few as 15 tests can be used to estimate the standard deviation; however, the calculated standard deviation should be increased by as much as 15% to account for the uncertainty in the estimate of the standard deviation. In the absence of sufficient information, a very conservative approach is required and the concrete is proportioned to produce relatively high average strengths.

If only a small number of test results are available, the estimates of the standard deviation and coefficient of variation become less reliable. When the number of strength test results is between 15 and 30, the calculated standard deviation, multiplied by the appropriate modification factors obtained from Table 4.1, which was taken from ACI 318, provides a Sufficiently conservative estimate to account for the uncertainty in the calculated standard deviation.

Table 4.1—Modification factors for standard deviation

Number of tests	Modification factors
Less than 15	See Table 4.2
15	1.16
20	1.08
25	1.03
30 or more	1.00

Table 4.2—Minimum required average strength without sufficient historical data

$f'_{cr} = f'_c + 6.9$ MPa (1000 psi)	when $f'_c < 20.7$ MPa (3000 psi)
$f'_{cr} = f'_c + 8.3$ MPa (1200 psi)	when $f'_c \geq 20.7$ MPa (3000 psi) and $f'_c \leq 34.5$ MPa (5000 psi)
$f'_{cr} = 1.10f'_c + 4.8$ MPa (700 psi)	when $f'_c > 34.5$ MPa (5000 psi)

3.2 Criteria for strength requirements

The minimum required average strength fcr′can be computed using Eq. (4-1a), (4-1b), Table 4.2, depending on whether the coefficient of variation or standard deviation is used. The value of fcr′will be the same for a given set of strength test results regardless of whether the coefficient of variation or standard deviation is used.

$$f'_{cr} = f'_c /(1 - zV) \qquad (4\text{-}1a)$$

$$f'_{cr} = f'_c + zs \qquad (4\text{-}1b)$$

where z is selected to provide a sufficiently high probability of meeting the specified strength, assuming a normal distribution of strength test results. In most cases, fc′ is replaced by a specified acceptance criterion, such as fc′ – 3.5 MPa or 0.90fc′.

Figure 4.3 shows that as the variability increases, fcr′ increases and thereby illustrates the economic value of good control.

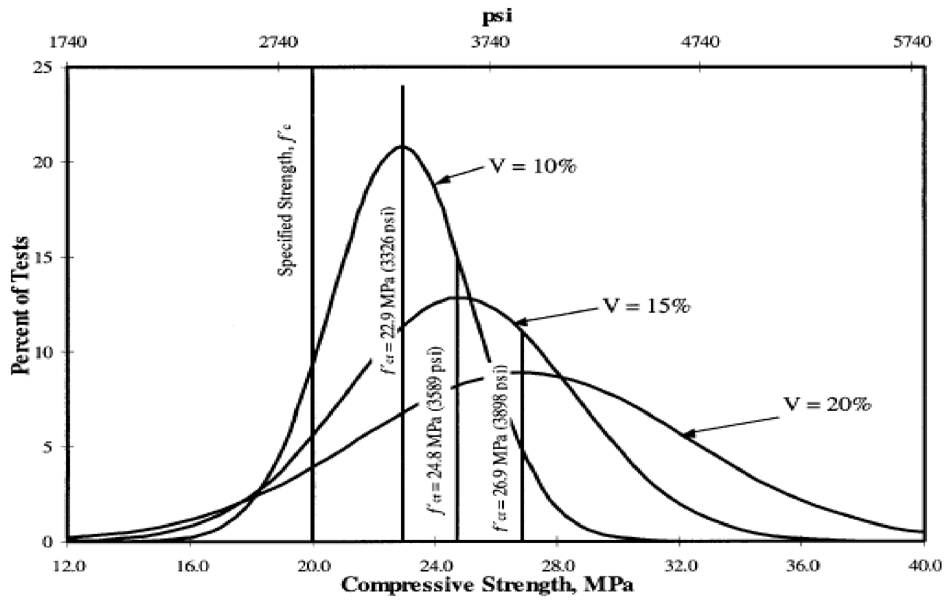

Fig. 4.3—Normal frequency curves for coefficients of variation of 10, 15, and 20%.

Table 4.3 provides values of z for various percentages of tests falling between the mean + zσ and the mean –zσ.

Table 4.3—Probabilities associated with values of *z*

Percentages of tests within ± *z*σ	Chances of falling below lower limit	*z*
40	3 in 10 (30%)	0.52
50	2.5 in 10 (25%)	0.67
60	2 in 10 (20%)	0.84
68.27	1 in 6.3 (15.9%)	1.00
70	1.5 in 10 (15%)	1.04
80	***1 in 10 (10%)***	***1.28***
90	1 in 20 (5%)	1.65
95	1 in 40 (2.5%)	1.96
95.45	1 in 44 (2.3%)	2.00
98	***1 in 100 (1%)***	***2.33***
99	1 in 200 (0.5%)	2.58
99.73	1 in 741 (0.13%)	3.00

Note: Commonly used values in bold italic.

The amount by which the required average strength fcr′ should exceed the specified compressive strength fc′ depends on the acceptance criteria specified for a particular project.

<u>The following are criteria examples used to determine the required average strength for various specifications or elements of specifications</u>. The numerical examples are presented in both SI and inch-pound units in a parallel format that have been hard converted and so are not exactly equivalent numerically.

<u>Criterion no. 1</u>—The engineer may specify a stated maximum percentage of individual, random strength tests results that will be permitted to fall below the specified compressive strength. This criterion is no longer used in the ACI 318 Building Code, but does occur from time to time in specifications based on allowable strength methods or in situations where the average strength is a fundamental part of the design methodology, such as in some pavement specifications. A typical requirement is to permit no more than 10%of the strength tests to fall below fc′. The specified strength in these situations will generally be between 21 and 35 MPa.

Standard deviation method—Assume sufficient data exist for which a standard deviation of 3.58 MPa has been calculated for a concrete mixture with a specified strength of 28 MPa. From Table 4.3, 10% o f the normal probability distribution lies more than 1.28 standard deviations below the mean. Using Eq. (4-1b)

$$f'_{cr} = f_c' + zs$$

$$f'_{cr} = 28 \text{ MPa} + 1.28 \times (3.58) \text{ MPa} = 32.6 \text{ MPa}$$

Therefore, for a specified compressive strength of 28 MPa, the concrete mixture should be proportioned for an average strength of not less than 32.6 MPa so that, on average, no more than 10% of the results will fall below fc′.

Coefficient of variation method—Assume sufficient data exist for which a coefficient of variation of 10.5% has been calculated for a concrete mixture with a specified strength of 28 MPa. From Table 4.3, 10% of the normal probability distribution lies more than 1.28 standard deviations below the mean. Using Eq. (4-1a)

$$f'_{cr} = f'_c/(1 - zV)$$

$$f'_{cr} = 28 \text{ MPa} /[1 - (1.28 \times 10.5/100)] = 32.3 \text{ MPa}$$

Therefore, for a specified compressive strength of 28 MPa, the concrete mixture should be proportioned for an averagestrength of not less than 32.3 MPa so that, on average, no morethan 10% of the results will fall below fc′.

4- EVALUATION OF DATA

Evaluation of strength data is required in many situations.Three commonly required applications are:

- Evaluation for mixture submittal purposes;
- Evaluation of level of control (typically called quality control); and
- Evaluation to determine compliance with specifications.

A major purpose of these evaluations is to identify departures from desired target values and, where possible, to assist with the formulation of an appropriate response. In all cases, the usefulness of the evaluation will be a function of the amount of test data and the statistical rigor of the analysis.

Numbers of tests - For a particular project, a sufficient number of tests should be made to ensure accurate representation of the concrete. A test is defined as the average strength of at least two specimens of the same age fabricated from a sample taken from a single batch of concrete. The frequency of concrete tests can be established on the basis of time elapsed or volume placed. The engineer should establish the number of tests needed based on job conditions.

Rejection of doubtful specimens - The practice of arbitrary rejection of strength test results that appear too far out of line is not recommended because the normal distribution anticipates the possibility of such results. Discarding test results indiscriminately can seriously distort the strength distribution, making analysis of results less reliable. Occasionally, the strength of one cylinder from a group made from a sample deviates so far from the others as to be highly improbable. If questionable variations have been observed during fabrication, curing, or testing of a specimen, the specimen should be rejected on that basis alone.

ASTM E 178 provides criteria for rejecting the test result for one specimen in a set of specimens. In general, the result from a single specimen in a set of three or more specimens can be discarded if its deviation from a test mean is greater than three times the previously established within-test standard deviation, and should be accepted with suspicion if its deviation is greater than two times the within test standard deviation. The test average should be computed from the remaining specimens. A test, that is, the average of all specimens of a single sample tested at the same age, should not be rejected unless it is very likely that the specimens are faulty. The test represents the best available estimate for the sample.

Applications

1- Calculate the required average strength (fcr') for a mix design if the specified compressive strength (characteristic strength) is 25 MPa. Assume sufficient data exist for which a standard deviation of 5.61 MPa has been calculated. Assume 10% of the normal probability distribution lies below the average compressive strength (i.e. 10 % of the results below the average strength, 90% confidence)

$$f'_{cr} = f_c{}' + zs$$

From Table

(4.3) 10 % probability corresponds to z=1.28, therefore,

Fcr' = 25 + 1.28*5.61 = 32.2 MPa

2- It is required to comment on the quality of a concrete for a raft foundation, the measurement of compressive strength of 17 test results. What is the actual compressive strength if the degree of confidence is 95% and do approve or disapprove this concrete, knowing that the specified (characteristic strength is 20 MPa).

Test Result No	Fc', MPa	Deviation	Squared deviation
1	21.8	2.8	7.84
2	18.4	-0.6	0.36
3	17.7	- 1.3	1.69
4	21.5	2.5	6.25
5	18.6	- 0.4	1.6
6	17.3	-1.7	2.89
7	20.9	1.9	3.61
8	14.2	-4.8	23.04
9	15.3	-3.7	13.69
10	18.7	- 0.3	0.09
11	18.1	- 0.9	0.81
12	19.3	0.3	0.09
13	14.7	- 4.3	18.49
14	21.3	2.3	5.29
15	23.1	4.1	16.81
16	20	1.0	1.0
17	22.1	3.1	9.61
	Average=19		Sum = 111.72

$$f'_{cr} = f'_c / (1 - zV)$$

$$f'_{cr} = 28 \text{ MPa} / [1 - (1.28 \times 10.5/100)] = 32.3 \text{ MPa}$$

]

Therefore this concrete is disapproved. Redesign should be carried out based on fc' = 14.7MPa.

3- Evaluate the results of compressive strength of two groups of concrete samples consider 95% degree of confidence. Then calculate the specified compressive strength of both groups of concrete based on only 90% degree of confidence.

	Concrete samples, Group 1	Concrete samples, Group 2
Measured compressive strength	395, 410, 412, 415	305, 385, 402, 540
Average, kg/cm^2	408	408
Range, kg/cm^2	20 (4.9 % from average)	235 (57.6 from average)
Deviations, kg/cm^2	-13, 2, 4, 7	-103, -23, -6, 132
Standard deviations, kg/cm^2	7.7 (0.77 MPa)	84.6 (8.46 MPa)
Coefficient of deviation, %	1.9	20.7
Level of quality control	Excellent (Table 3.2)	Poor (Table 3.3)
Specified strength (95% confidence)	395	269
Specified strength (90% confidence)	398	300

4- Comment on the following test results of samples of a concrete cover for raft foundation

	7-day test result, kg/cm^2	28-day results, kg/cm^2	Additional 28-day results, kg/cm^2
1	209.5	230	192.6
2	179.7	269.1	115.3
3	147.6	121.4	212.5
4	106.4	306	157.1
5	76.7	158	189.6
6	187.9	202.2	173.1
7	167.3	145.5	129.4
8	176	146	200.6
9	135	130.6	102.5
10	135.4	198.4	178
11	130	150.5	170.3
12	57.9	217.2	248.2
13	129.3	178.8	237
14	123.4	182.3	228.6
15	118.9	172.4	89.6
16	112.6	131.5	157.3
17	123.1	247.5	161.2
18	123.9	186.8	144.1
19	104.6	142.7	167.4
20	93.6	163.1	141.3
21	105.3	82	
22	181.6	147.5	
23	182.2	150.3	
24	150.8	183.1	
25	204.3	243.6	

Statistical Functions

Average of the 45 test results at 28 day = 175.16 kg/cm^2
Standard deviation = 47.37 kg/cm^2 (4.7
MPa) Coefficient of variation = 27.05 %
Max value = 306 kg/cm^2
Min value = 82 kg/cm^2
Range = 224 kg/cm^2

Analysis of Results

- Based on Table 3.2 for standard deviation 4.7 MPa, the concrete is at the upper limit of "**Fair**"
- Based on Table 3.3, for coefficient of variation of 27.05 %, the concrete is "**Poor**"

Specified strength = 175.16 (1-1.28*.2705) = 114.5 kg/cm2 (90 %
confidence) Specified strength = 175.16 (1-1.64*.2705) = 97.5 kg/cm2 (95 %
confidence)

% of discount = (target strength – actual average specified strength)/ Target strength
Assume target strength = 225 kg/cm^2
% discount = (200-114.5)/200 = 0.4275

Total discount inUSD = cost per 1m^3*amount of concrete* % of discount

= 204 USD * 155 * 0.4275 =
13517.6 USD

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UNIT – IV – ADVANCED CONCRETE TECHNOLOGY– SCIA7001

UNIT-IV

SPECIAL CONCRETE

Light weight concrete, Fly ash concrete, Fibre reinforced concrete, Sulphur impregnated concrete, Polymer Concrete, Super plasticized concrete, hyper plasticized concrete, Epoxy resins and screeds for rehabilitation - properties and applications - high performance concrete. High performance fiber reinforced concrete, self compacting-concrete.

LIGHTWEIGHT CONCRETE

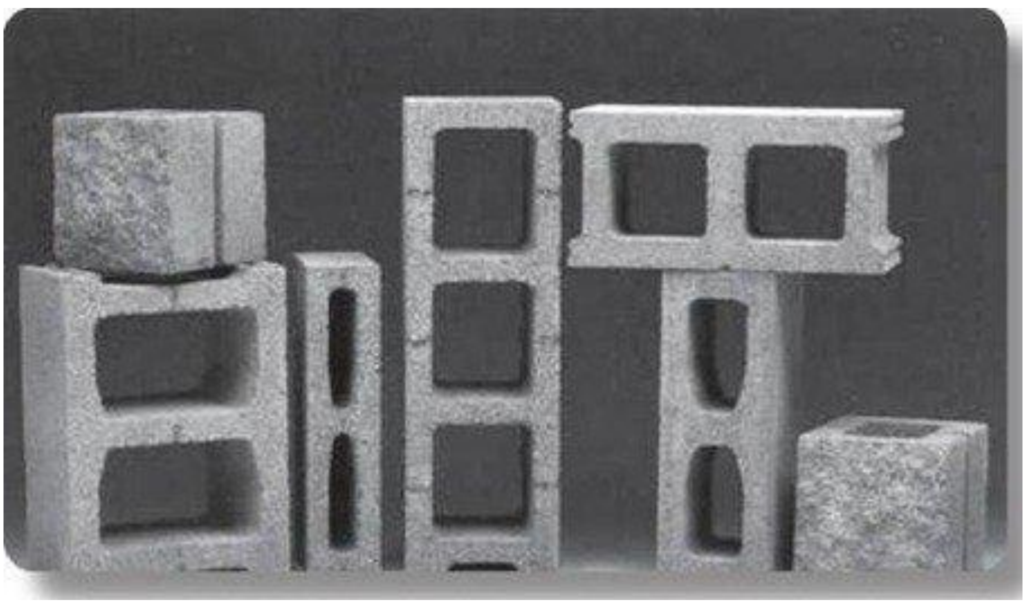
The use of LWC (Lightweight concrete) has been a feature in the construction industry for centuries, but like other material the expectations of the performance have raised and now we are expecting a consistent, reliable material and predictable characteristics.

Structural LWC has an in-place density (unit weight) on the order of 90 to 115 lb / ft^3 (1440 to 1840 kg/m^3) compared to normal weight concrete a density in the range of 140 to 150 lb/ft^3 (2240 to 2400 kg/m^3). For structural applications the concrete strength should be greater than 2500 psi (17.0 MPa). The concrete mixture is made with a lightweight coarse aggregate. In some cases a partion or the entire fine aggregates may be a lightweight product. Lightweight aggregates used in structural lightweight concrete are typically expanded shale, clay or slate materials that have been fired in a rotary kiln to develop a porous structure. Other products such as air-cooled blast furnace slag are also used. There are other classes of non-structural LWC with lower density made with other aggregate materials and higher air voids in the cement paste matrix, such as in cellular concrete.

HISTORICAL OF LWC

Generally, the properties of LWC can be indicated by doing laboratory testing, but the overall performance of the material can only be demonstrated adequately by its performance in the field by testing LWC structure under service. LWC has been successfully used for marine applications and in shipbuilding. LWC ships were produced in the USA during the 1914-1918 war, and their success led to the production of the USS Selma (a war ship). In both 1953 and 1980 the Selma's durability was assessed by taking cored samples from the water line area. On both occasion little corrosion was noted.

In 1984, Thomas A. Holm estimated that there were over 400 LWC bridges throughout the world especially in USA and Canada. The research carried out by The Expanded Clay and Slate Institute proves that most of the bridges appeared to be in good condition. According to ACI Material Journal by Diona Marcia, Andrian Loani, Mihai Filip and Ian Pepenar (1994), it was found that in Japan LWC had been used since 1964 as a railway station platform. The study on durability was carried out in 1983 has proven that LWC exhibited similar carbonation depths as normal concrete. Even though some cracks were reported, but these posed no structure problems. A second structure comprising both LWC and normal concrete which had been in sea water for 13 years was examined for salt penetration.



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 ***lightweight aggregate concrete.***

2. By introducing large voids within the concrete or mortar mass; these voids should be clearly distinguished from the extremely fine voids produced by air entrainment. This types of concrete is variously knows **as *aerated, cellular, foamed*** or ***gas concrete.***
3. By omitting the fine aggregate from the mix so that a large number of interstitial voids is present; normal weight coarse aggregate is generally used. This concrete as ***no-fines*** concrete.

LWC can also be classified according to the purpose for which it is to be used: it can distinguish between structural lightweight concrete (ASTM C 330-82a), concrete used in masonry units (ASTM C 331-81), and insulating concrete (ASTM C 332-83). This classification of structural lightweight concrete is based on a minimum strength: according to ASTM C 330-82a, the 28-day cylinder compressive strength should not be less than 17 MPa (2500 psi). The density (unit weight) of such concrete (determined in the dry state) should not exceed 1840 kg/m^3 (115 lb/ft^3), and is usually between 1400 and 1800 kg/m^3 (85 and 110 lb/ft^3). On the other hand, masonry concrete generally has a density between 500 and 800 kg/m^3 (30 and 50 lb/ft^3) and a strength between 7 and 14 MPa (1000 and 2000 psi).

TYPES OF LWC

1. **LWA CONCRETE**

In the early 1950s, the use of lightweight concrete blocks was accepted in the UK for load bearing inner leaf of cavity walls. Soon thereafter the development and production of new types of artificial LWA (Lightweight aggregate) made it possible to introduce LWC of high strength, suitable for structural work. These advances encouraged the structural use of LWA concrete, particularly where the need to reduce weight in a structure was in a structure was an important consideration for design or for economy.

Listed below are several types of LWA suitable for structural reinforced concrete:-

i. Pumice – is used for reinforced concrete roof slab, mainly for industrial roofs in Germany.

ii. Foamed Slag – was the first LWA suitable for reinforced concrete that was produced in large quantity in the UK.

iii. Expanded Clays and Shales – capable of achieving sufficiently high strength for prestressed concrete. Well established under the trade names of Aglite and Leca (UK), Haydite, Rocklite, Gravelite and Aglite (USA).

iv. Sintered Pulverised – fuel ash aggregate – is being used in the UK for a variety of structural purposes and is being marketed under the trade name Lytag.

1. **AERATED CONCRETE**

Concrete of this type has the lowest density, thermal conductivity and strength. Like timber it can be sawn, screwed and nailed, but there are non-combustible. For works insitu the usual methods of aeration are by mixing in stabilized foam or by whipping air in with the aid of an air entraining agent. The precast products are usually made by the addition of about 0.2 percent aluminums powder to the mix which reacts with alkaline substances in the binder forming hydrogen bubbles. Air-cured aerated concrete is used where little strength is required e.g. roof screeds and pipe lagging. Full strength development depends upon the reaction of lime with the siliceous aggregates, and for the equal densities the strength of high pressure steam cured concrete is about twice that of air-cured concrete, and shrinkage is only one third or less.

Aerated concrete is a lightweight, cellular material consisting of cement and/or lime and sand or other silicious material. It is made by either a physical or a chemical process during which either air or gas is introduced into a slurry, which generally contains no coarse material. Aerated concrete used as a structural material is usually high-pressure steam-cured. It is thus factory-made and available to the user in precast units only, for floors, walls and roofs. Blocks for laying in mortar or glue are manufactured without any reinforcement. Larger units are reinforced with steel bars to resist damage through transport, handling and superimposed loads. Autoclaved aerated concrete, which was originally developed in Sweden in 1929, is now manufactured all over the world.

2. NO-FINES CONCRETE

The term no-fines concrete generally means concrete composed of cement and a coarse (9-19mm) aggregate only (at least 95 percent should pass the 20mm BS sieve, not more than 10 percent should pass the 10mm BS sieve and nothing should pass the 5mm BS sieve), and the product so formed has many uniformly distributed voids throughout its mass. No-fines concrete is mainly used for load bearing, cast in situ external and internal wall, non load bearing wall and under floor filling for solid ground floors (CP III: 1970, BSI). No-fines concrete was introduced into the UK in 1923, when 50 houses were built in Edinburgh, followed a few years later by 800 in Liverpool, Manchester and London.

This description is applied to concrete which contain only a single size 10mm to 20mm coarse aggregate (either a dense aggregate or a light weight aggregate such as sintered PFA). The density is about two-third or three quarters that of dense concrete made with the same aggregates. No-fines concrete is almost always cast in situ mainly as load bearing and non load bearing walls including in filling walls, in framed structures, but sometimes as filling below solids ground floors and for roof screeds.

No-fines concrete is thus an agglomeration of coarse aggregate particles, each surrounded by a coating of cement paste up to about 1·3 mm (0·05 in.) thick. There exist, therefore, large pores within the body of the concrete which are responsible for its low strength, but their large size means that no capillary movement of water can take place. Although the strength of no-fines concrete is considerably lower than that of normal-weight concrete, this strength, coupled with the lower dead load of the structure, is sufficient in buildings up to about 20 storeys high and in many other applications.

LWC CLASSIFICATION

LWC can be classification:-

i. Low density concrete

ii. Moderate strength concrete

iii. Structural concrete

i. LOW DENSITY CONCRETE

These are employing chiefly for insulation purposes. With low unit weight, seldom exceeding 800 kg/m^3, heat insulation value are high. Compressive strength are low, regarding from about 0.69 to 6.89 N/mm2.

ii. MODERATE STRENGTH CONCRETE

The use of these concrete requires a fair degree of compressive strength, and thus they fall about midway between the structural and low density concrete. These are sometimes designed as ‘fill’ concrete. Compressive strength are approximately 6.89 to 17.24 N/mm^2 and insulation values are intermediate.

iii. STRUCTURAL CONCRETE

Concrete with full structural efficiency contain aggregates which fall on the other end of the scale and which are generally made with expanded shale, clay, slates, slag, and fly-ash. Minimum compressive strength is 17.24 N/mm^2. Most structural LWC are capable of producing concrete with compressive strength in excess of 34.47 N/mm^2. Since the unit weight of structural LWC are considerably greater than those of low density concrete, insulation efficiency is lower. However, thermal insulation values for structural LWC are substantially better than NWC.

THE USE OF LWC

- Screeds and thickening for general purposes especially when such screeds or thickening and weight to floors roofs and other structural members.
- Screeds and walls where timber has to be attached by nailing.
- Casting structural steel to protect its against fire and corrosion or as a covering for architectural purposes.
- Heat insulation on roofs.
- Insulating water pipes.
- Construction of partition walls and panel walls in frame structures.

- Fixing bricks to receive nails from joinery, principally in domestic or domestic type construction.
- General insulative walls.
- Surface rendered for external walls of small houses.
- It is also being used for reinforced concrete.

ADVANTAGES OF USING LWC

1. Reduced dead load of wet concrete allows longer span to be poured unpropped. This save both labour and circle time for each floor.
2. Reduction of dead load, faster building rates and lower haulage and handling costs. The eight of the building in term of the loads transmitted by the foundations is an important factor in design, particular for the case of tall buildings. The use of LWC has sometimes made its possible to proceed with the design which otherwise would have been abandoned because of excessive weight. In frame structures, considerable savings in cost can be brought about by using LWC for the construction floors, partition and external cladding.
3. Most building materials such as clay bricks the haulage load is limited not by volume but by weight. With suitable design containers much larger volumes of LWC can haul economically.
4. A less obvious but nonetheless important characteristics of LWC is its relatively low thermal conductivity, a property which improves with decreasing density in recent years, with the increasing cost and scarcity of energy sources, more attention has been given the formerly to the need for reducing fuel consumption while maintaining, and indeed improving, comfort conditions buildings. The point is illustrated by fact that a 125mm thick solid wall of aerated concrete will give thermal insulation about four times greater than that of a 230mm clay brick wall.

DURABILITY OF LWC

Durability is defined as the ability of a material to withstand the effect of its environment. In a building material as chemical attack, physical stress, and mechanical assault:-

1. Chemical attack is as aggregate ground-water particularly sulphate, polluted air, and spillage of reactive liquids LWC has no special resistant to these agencies: indeed, it is generally move porous than the ordinary Portland cement. It is not recommended for use below damp-course. A chemical aspects of durability is the stability of the material itself, particularly at the presence of moisture.
2. Physical stresses to which LWC is exposed are principally frost action and shrinkage and temperature stresses. Stressing may be due to the drying shrinkage of the concrete or to differential thermal movements between dissimilar materials or to other phenomena of a similar nature. Drying shrinkage commonly causes cracking of LWC if suitable precautions are not taken.
3. Mechanical damage can result from abrasion or impact excessive loading of flexural members. The lightest grades of LWC are relatively soft so that they subject to some abrasion were they not for other reasons protected by rendering.

POLYMER CONCRETE

INTRODUCTION

Polymer concrete is part of group of concretes that use polymers to supplement or replace cement as a binder. The types include polymer-impregnated concrete, polymer concrete, and polymer-Portland-cement concrete. Polymers in concrete have been overseen by Committee 548 of the American Concrete Institute since 1971

COMPOSITION:

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

USES:

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

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

Advantages of polymer concrete include:

- 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
- Lighter weight (only somewhat less dense than traditional concrete, depending on the resin content of the mix)
- May be vibrated to fill voids in forms
- Allows use of regular form-release agents (in some applications)
- Dielectric

DISADVANTAGES:

- Product hard to manipulate with conventional tools such as drills and presses due to its density. Recommend getting pre-modified product from the manufacturer

Small boxes are more costly when compared to its precast counterpart however pre cast concretes induction of stacking or steel covers quickly bridge the gap

Polymer-impregnated concrete

Introduction:

Polymers have been employed as concrete admixtures to improve durability of the concrete structures that have degraded due to exposure to weather and polluted environments. Based on the mode of their addition polymer cement concrete is classified as – Polymer Modified Cement Concrete or Mortars (PMC/PMM), Polymer Concrete or Mortars (PC/PM), Polymer Impregnated Concrete or Mortars (PIC/PIM) . The latter is one the oldest polymer cement composites and is prepared by impregnating the monomer into the concrete or mortar structures and then by polymerizing the monomer. PICs possess superior strength, chemical resistance and low water absorption compared to other polymer cement composites. Some of the applications where these composites find use are reactors, bridges, pipes, storage bunkers for chemicals and structures in marine environments. Conventionally PICs are prepared by immersing the precast concrete structure in a mixture of a monomer and an initiator for a few hours at room temperature and polymerizing the monomer by thermal methods. This results in monomer loss during polymerization at high temperature thus affecting the properties of the PIC. In this work we describe a method to increase the monomer impregnation thereby reducing such losses. The monomer is introduced into the voids and pores of the precast concrete by subjecting the experimental setup to ultrasonic vibrations thereby enhancing the chances of monomer impregnation to a greater degree than the conventional procedure. The impregnated specimens are dried, vacuum packed to prevent monomer loss and subsequently polymerized using microwaves. When compared with composites prepared by conventional methods and ordinary precast concrete, it was observed that this procedure increased the degree of polymerization of the monomer in the concrete structures thereby improving both the mechanical and chemical resistant properties of the composite.

Experimental program

The precast cement mortar specimens used were first impregnated with methyl methacrylate and then polymerized using two different procedures. The mechanical and chemical resistant properties of these PICs after exposure to sulphuric acid for different periods were evaluated and their microstructures analyzed. Materials Compressive strength was evaluated for precast cement mortars cubical specimens of dimensions 5cm X 5cm X 5cm weighing around 250g and flexural strength for specimens of dimensions 4cm X 4cm X 16cm weighing 530g approximately. Ordinary Portland cement and sand conforming to Korean standard KS L 5100 were used in the preparation of the specimens. The water to cement ratio was 0.48 while the cement, sand and water were mixed in the proportion 1:2.45:0.48. Impregnation and Polymerization The precast mortar specimens were dried in a hot air oven (Sam woo Science make) at 80℃ for 12 hours. These were annealed to room temperature and weighed before impregnation. The monomer, Methyl methacrylate (MMA) was mixed with 1% by weight of 2, 2'-Azobisisobutyronitrile (AIBN) as initiator using a magnetic stirrer. The mortar samples were immersed into this mixture and impregnated by placing the setup in a water bath inside an ultrasound vibration system for 4.5 hours at room temperature. The samples were dried, weighed and vacuum packed in PET packets to prevent loss of monomer during polymerization. The samples were thermally polymerized by two different procedures viz. using conventional methods and microwaves. In the conventional method the packed impregnated mortar samples were immersed in hot water at 80℃ to achieve uniform heating for three hours . Polymerization of the specimens in the microwave reactor was done at a frequency of 2450MHz (400W) at 80℃ for two hours. After polymerization the samples were removed from the PET packets, cooled to room temperature and weighed. Performance The mechanical properties evaluated for the PIC specimens were compressive and flexural strengths. The durability of these composites when exposed to various chemical environments was evaluated by calculating the weight loss. Compressive strength is a basic property used to assess the performance of hardened concrete made for a particular application. It is calculated by dividing the maximum load applied when the cubical specimen fails by its cross sectional area resisting the load. In this work the cubical specimens of 5cm X 5cm X 5cm were employed and the evaluation of these properties was performed in accordance to KS L 5105 standards (5). The maximum load needed to break the conventional cement mortar and PIC samples was determined using a Servo UTM US-200. In concrete, cracks can propagate very easily in tension and excessive cracking of concrete causes serviceability and durability problems. In this work, the flexural strengths of conventional cement mortar and PIC specimens of dimensions 4cm X 4cm X 16cm were evaluated according to ASTM C293 - 08. A Digital Flexure Tensile Tester HJ-1171 was employed to calculate the flexural strengths of the conventional cement mortar and the PIC specimens. The decrease in durability of concrete structures due to increasing environmental pollution is a matter of great concern. Many admixtures including polymers are employed to increase this durability. In this work, two series of specimens viz. conventional cement mortar and PIC, were weighed and immersed in 5M sulphuric acid for different periods of exposure time – 3,5,7 and 14 days to assess the extent of damage caused due to the interaction of the samples with the external chemicals. The cumulative weight losses of the PIC specimens on exposure to the acid were compared to those obtained for ordinary Portland cement mortar samples

Polymer-cement concrete (PCC):

Polymer-cement concrete also called polymer-Portland-cement concrete (PPCC) and latex-modified concrete (LMC), is made by Portland cement and aggregate just like ordinary concrete but organic polymers dispersed in water (latex) are added at the time of mixing. The organic polymer is a substance composed of thousands of simple molecules, called monomers, combined into large molecules in a process called polymerization. The polymer is called a homopolymer if it is made by the polymerization of one monomer, and a copolymer if two or more monomers are polymerized. By adding polymer dispersions to the concrete mixtures, bond strength to concrete substrates, flexibility and impact resistance, resistance to penetration by water and by dissolved salts, and resistance to freezing and thawing are improved. Polymers made by emulsion polymerization are the most widely used. Styrene butadiene and acrylic latexes are the most effective and widely used materials for concrete restoration, but vinyl acetate is also used. Generally, 10 to 20% of polymer solids are usually added with respect to the mass of cement and typical *w/c* for workable materials used for repair range from 0.30 to 0.40 for mixes with latexes, and 0.25 to 0.35 for mixtures with epoxies.

Fiber-reinforced concrete:

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

Historical perspective

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

Effect of fibers in concrete

Fibers are usually used in concrete to control cracking due to plastic shrinkage and to drying shrinkage. They also reduce the permeability of concrete and thus reduce bleeding of water. Some types of fibers produce greater impact–, abrasion–, and shatter–resistance in concrete. Generally fibers do not increase the flexural strength of concrete, and so cannot replace moment–resisting or structural steel reinforcement. Indeed, some fibers actually reduce the strength of concrete.

The amount of fibers added to a concrete mix is expressed as a percentage of the total volume of the composite (concrete and fibers), termed "volume fraction" (V_f). V_f typically ranges from 0.1 to 3%. The aspect ratio (l/d) is calculated by dividing fiber length (l) by its diameter (d). Fibers with a non-circular cross section use an equivalent diameter for the calculation of aspect ratio. If the fiber's modulus of elasticity is higher than the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material. Increasing the aspect ratio of the fiber usually segments the flexural strength and toughness of the matrix. However, fibers that are too long tend to "ball" in the mix and create workability problems.

Some recent research indicated that using fibers in concrete has limited effect on the impact resistance of the materials. This finding is very important since traditionally, people think that ductility increases when concrete is reinforced with fibers. The results also indicated that the use of micro fibers offers better impact resistance to that of longer fibers.

The High Speed tunnel linings incorporated concrete containing 1 kg/m^3 of polypropylene fibers, of diameter 18 & 32 μm, giving the benefits noted below.

As for pavements, the most prevalent use for FRC is at toll plazas where nonmetallic fibers are used in lieu of metallic reinforcement since they can disrupt electronic toll reader's signals.

FIBER TYPES

Fiber types for use in FRC Applications come in many sizes, shapes, colors and flavors. Please contact the various manufacturers, listed in the "CONTACT US" section for additional technical literature and dosage recommendations.

Steel Fibers: These fibers are generally used for providing concrete with enhanced toughness and post-crack load carrying capacity. Typically loose or bundled, these fibers are generally made from carbon or stainless steel and are shaped into varying geometries such as crimped, hooked-end or with other mechanical deformations for anchorage in the concrete. Fiber types are classified within ACI 544 as Types I through V and have maximum lengths ranging from 1.5" to 3" (30 – 80 mm) and can be dosed at 10 to 100 lbs/yd (6 to 67 kg/m^3).

Micro-synthetic fibers: These fibers are generally used for the protection and mitigation of plastic shrinkage cracking in concrete. Most fiber types are manufactured from polypropylene, polyethylene, polyester, nylon and other synthetic materials such as carbon, aramid and other acrylics. These fiber types are generally dosed at low volumes ranging from 0.03 to 0.2% by volume of concrete – 0.5 to 3.0 lbs/yd (0.3 to 0.9 kg/m^3).

Macro-synthetic fibers: This newer class of fibers has emerged over the past 15 years as a suitable alternate to steel fibers when dosed properly. Typical materials include polypropylene and other polymer blends having the same physical characteristics as steel fibers (length, shape, etc.), These fibers can be dosed from 3 to 20 lbs/yd (1.8 to 12 kg/m^3).

Glass Fibers: GFRC (Glass Fiber Reinforced Concrete) has been predominantly used in architectural applications and modified cement based panel structures.

Cellulose Fibers: manufactured from processed wood pulp products, cellulose fibers are used in a similar manner to micro-synthetic fibers for the control and mitigation of plastic shrinkage cracking.

Natural Fibers: Not typically used in commercial applications of fiber reinforced concrete, natural fibers are used to reinforce cement based products in applications around the world and include materials such as coconut, sisal, jute and sugarcane. These materials come in varying lengths, geometries and material characteristics.

PVA Fibers: Poly-vinyl alcohol fibers are synthetic made fibers that when used at higher volumes, can alter the flexural and compressive performance of concrete

Specialty Fibers: This classification of fibers covers materials not described above and generally pertains to newly manufactured or specified materials not common to the above categories.

Steel & Micro / Macro blends: A recent development in the field of fiber reinforced concrete that has emerged in the marketplace has been the combination or blending of steel and / or macro-synthetic fibers with various types of micro-fibers to help control plastic shrinkage cracking (ie: micro-synthetics) while at the same time providing concrete with enhanced toughness and post-crack load carrying capacity achieved only with the use of steel and macro-synthetic fibers. These fibers are typically dosed at the prevailing

Benefits

Polypropylene and Nylon fibers can:

- Improve mix cohesion, improving pumpability over long distances
- Improve freeze-thaw resistance
- Improve resistance to explosive spalling in case of a severe fire

- Improve impact resistance– and abrasion–resistance
- Increase resistance to plastic shrinkage during curing
- Improve structural strength
- Reduce steel reinforcement requirements
- Improve ductility
- Reduce crack widths and control the crack widths tightly, thus improving durability

Steel fibers can:

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

Blends of both steel and polymeric fibers are often used in construction projects in order to combine the benefits of both products; structural improvements provided by steel fibers and the resistance to explosive spalling and plastic shrinkage improvements provided by polymeric fibers.

In certain specific circumstances, steel fiber or macro synthetic fibers can entirely replace traditional steel reinforcement bar ("rebar") in reinforced concrete. This is most common in industrial flooring but also in some other precasting applications. Typically, these are corroborated with laboratory testing to confirm that performance requirements are met. Care should be taken to ensure that local design code requirements are also met, which may impose minimum quantities of steel reinforcement within the concrete. There are increasing numbers of tunnelling projects using precast lining segments reinforced only with steel fibers.

Micro-Rebar has also been recently tested and approved to replace traditional reinforcement in vertical walls designed in accordance with ACI 318.

Mixing of fibers in concrete:

The mix should have a uniform dispersion of the fibers in order to prevent segregation or balling of the fibers during mixing. Most balling occurs during the fiber addition process. Increase of aspect ratio, volume percentage of fiber, and size and quantity of coarse aggregate will intensify the balling tendencies and decrease the workability. To coat the large surface area of the fibers with paste, experience indicated that a water cement ratio between 0.4 and 0.6, and minimum cement content of 400 kg/m are required. Compared to conventional concrete, fiber reinforced concrete mixes are generally characterized by higher cement factor, higher fine aggregate content and smaller size coarse aggregate.

A mix generally requires more vibration to consolidate the mix. External vibration is preferable to prevent fiber segregation. Metal trowels, tube floats, and rotating power floats can be used to finish the surface. Mechanical Properties of FRC Addition of fibers to concrete influences its mechanical properties which significantly depend on the type and percentage of fiber.

APPLICATIONS

Potential projects suited to the use of fiber reinforced concrete are listed below. Where possible, the members of the FRCA have submitted project profiles with the use of fibers in the following applications

Residential: including driveways, sidewalks, pool construction with shotcrete, basements, colored concrete, foundations, drainage, etc.

Commercial: exterior and interior floors, slabs and parking areas, roadways and

Warehouse / Industrial: light to heavy duty loaded floors and roadways

Highways / Roadways / Bridges: conventional concrete paving, SCC, white-toppings, barrier rails, curb and gutter work, pervious concrete, sound attenuation barriers, etc.

Ports and Airports: runways, taxiways, aprons, seawalls, dock areas, parking and loading ramps.

Waterways: dams, lock structures, channel linings, ditches, storm-water structures, etc.

Mining and Tunneling: Precast segments and schotcrete, which may include tunnel lining, shafts, slope stabilization, sewer work, etc.

Elevated Decks: including commercial and industrial composite metal deck construction and elevated formwork at airports, commercial buildings, shopping centers, etc.

Agriculture: farm and animal storage structures, walls, silos, paving, etc.

Precast Concrete and Products: architectural panels, tilt-up construction, walls, fencing, septic tanks, burial vaults, grease trap structures, bank vaults and sculptures

The following are some of the advantages fibers in structural behavior:

Fibers with end anchorage and Properties and Applications of Fiber Reinforced Concrete 51 high aspect ratio were found to have improved effectiveness.

It was shown that for the same length and diameter, crimped-end fibers can achieve the same properties as straight fibers using 40 percent less fibers.

The presence of fibers may alter the failure mode of cylinders, but the fiber effect will be minor on the improvement of compressive strength values (0 to 15 percent).

Modulus of elasticity of FRC increases slightly with an increase in the fibers content. It was found that for each 1 percent increase in fiber content by volume there is an increase of 3 percent in the modulus of elasticity.

The flexural strength was reported to be increased by 2.5 times using 4 percent fibers.

Toughness For FRC, toughness is about 10 to 40 times that of plain concrete. Splitting Tensile Strength The presence of 3 percent fiber by volume was reported to increase the splitting tensile strength of mortar about 2.5 times that of the unreinforced one.

The addition of fibers increases fatigue strength of about 90 percent and 70 percent of the static strength at 2 x 106 cycles for non-reverse and full reversal of loading, respectively. Impact Resistance The impact strength for fibrous concrete is generally 5 to 10 times that of plain concrete depending on the volume of fiber.

Corrosion of Steel and fibrous mortar to outdoor weathering in an industrial atmosphere showed no adverse effect on the strength properties. Corrosion was found to be confined only to fibers actually exposed on the surface. Steel fibrous mortar continuously immerse in seawater for 10 years exhibited a 15 percent loss compared to 40 percent strength decrease of plain mortar.

The use of fibers eliminates the sudden failure characteristic of plain concrete beams. It increases stiffness, torsional strength, ductility, rotational capacity, and the number of cracks with less crack width. Shear Addition of fibers increases shear capacity of reinforced concrete beams up to 100 percent. Addition of randomly distributed fibers increases shear-friction strength, the first crack strength, and ultimate strength. Column The increase of fiber content slightly increases the ductility of axially loaded specimen. The use of fibers helps in reducing the explosive type failure for columns. High Strength Concrete Fibers increases the ductility of high strength concrete.

The use of high strength concrete and steel produces slender members. Fiber addition will help in controlling cracks and deflections. Cracking and Deflection Tests have shown that fiber reinforcement effectively controls cracking and deflection, in addition to strength improvement. In conventionally reinforced concrete beams, fiber addition increases stiffness, and reduces deflection. Applications The uniform dispersion of fibers throughout the concrete mix provides isotropic properties not common to conventionally reinforced concrete.

Some developments in fiber-reinforced concrete

An FRC sub-category named High-Performance Fiber Reinforced Concrete (HPFRC) claims 500 times more resistance to cracking and 40 percent lighter than traditional concrete. HPFRC claims it can sustain strain-hardening up to several percent strain, resulting in a material ductility of at least two orders of magnitude higher when compared to normal concrete or standard fiber-reinforced concrete. HPFRC also claims a unique cracking behavior. When loaded to beyond the elastic range, HPFRC maintains crack width to below 100 µm, even when deformed to several percent tensile strains. Field results with HPFRC and The Michigan Department of Transportation resulted in early-age cracking.

Recent studies performed on a high-performance fiber-reinforced concrete in a bridge deck found that adding fibers provided residual strength and controlled cracking. There were fewer and narrower cracks in the FRC even though the FRC had more shrinkage than the control. Residual strength is directly proportional to the fiber content.

A new kind of natural fiber-reinforced concrete (NFRC) made of cellulose fibers processed from genetically modified slash pine trees is giving good results. The cellulose fibers are longer and greater in diameter than other timber sources. Some studies were performed using waste carpet fibers in concrete as an environmentally friendly use of recycled carpet waste. A carpet typically consists of two layers of backing (usually fabric from polypropylene tape yarns), joined by $CaCO_3$ filled styrene-butadiene latex rubber (SBR), and face fibers (majority being nylon 6 and nylon 66 textured yarns). Such nylon and polypropylene fibers can be used for concrete reinforcement. Other ideas are emerging to use recycled materials as fibers: recycled Polyethylene terephthalate (PET) fiber, for example.

Steel fibre-reinforced shotcrete (SFRS) is a kind of spray concrete (shotcrete) with steel fibres added

SULPHUR IMPREGNATED CONCRETE

Sulphur, sand and coarse aggregate are the ingredients of this concrete. Molten sulphur is added to the preheated aggregates in a mixture. The hot mix is immediately transferred into the moulds to fill them completely. The products manufactured with sulphur concrete need no curing and the moulds can be stripped immediately as the sulphur solidifies rapidly under normal temperatures. One of the major advantages of these products is that they can be remoulded and concrete can be reused with minimum or no wastage. These products have very low absorption and less permeability.

Strength upto 44 MPa have been reported when 30 % of sulphur, 50% of sand and 20% of coarse aggregate are mixed. These are therefore versatile for use as precast slab elements of canal and tunnel linings.

Plasticizers / Water Reducers

Plasticizers, also called Water Reducers, impart Plasticizing effect in wet concrete; are organic substances or combination of organic and inorganic substances. Basic constituents of Plasticizers are lignosulphonates, their derivatives; acid of hydroxylated carboxylic acids, their derivatives; and Carbohydrates. These are primarily used for their water reducing capacity; maintaining the desired workability of a concrete mix. In other words it has a property of enhancing workability at a given water-cement ratio in compare to concrete mix without Plasticizers.

Plasticizers indirectly add strength to hardened concrete by enhancing workability of a concrete mix during its mixing and placing thereby allowing reduction in water-cement (W/C) ratio. Reduction in water cement ratio increases the strength of concrete. Also, reduction in cement content for a given strength thereby decreases in heat of hydration and cost saving is also possible by the use of Plasticizers.

Plasticizers are added in the amount of 0.1% to 0.5% by weight of cement. The reduction in water content for the given degree of workability is in the range of 5% to 15% by addition of these Plasticizers in above doses.

Plasticizers, from the above origin could also entrain air more than the acceptable limit while increasing workability that may result in decrease in strength. So, only prescribed dosages should be used.

Super plasticizers / High Range Water Reducers

Superplasticizers are the improved chemical admixtures over Plasticizers with highly effective Plasticizing effects on wet concrete. Superplasticizers result in substantial enhancement in workability at a given water-cement ratio. For a constant workability, reduction of water content up to 30% may be achieved by the use of Superplasticizers. Superplasticizers can be used at the higher dosages than conventional Plasticizers in the range of 0.5% to 3% by weight of cement. Superplasticizers are organic poly-electrolytes; that belong to the category of polymeric dispersants. Some of the Superplasticizers are synthetic while others are derived from natural products.

High Performance Concrete (HPC)

Concrete has renewed its definition from just being a mixture of cement, sand and aggregate along with water. It used to be so. Advancement in Concrete Technology has revolutionized this "mixture" of above mentioned various conventional ingredients in the fulfillment of several desired properties.

Concrete nowadays has become much more worker friendly, stronger & more durable; than ever before with various other desirable properties. Concrete with such advanced diversified properties is referred as High Performance (HPC). HPC signifies superior concrete performance during wet stage (mixing & placing process); with higher strength in hardened stage along with a greater durability in long-term with respect to Normal concrete.

High-performance concrete characteristics are developed for particular applications and environments; some of the properties that may be required include:

- High strength
- High early strength
- High modulus of elasticity
- High abrasion resistance
- High durability and long life in severe environments
- Low permeability and diffusion
- Resistance to chemical attack
- High resistance to frost and deicer scaling damage
- Toughness and impact resistance
- Volume stability
- Ease of placement
- Compaction without segregation
- Inhibition of bacterial and mold growth

High-performance fiber-reinforced cementitious composites

High-performance fiber-reinforced cementitious composites (HPFRCCs) are a group of fiber-reinforced cement-based composites which possess the unique ability to flex and selfstrengthen before fracturing. This particular class of concrete was developed with the goal of solving the structural problems inherent with today's typical concrete, such as its tendency to fail in a brittle manner under excessive loading and its lack of long-term durability. Because of their design and composition, HPFRCCs possess the remarkable ability to strain harden under excessive loading. In layman's terms, this means they have the ability to flex or deform before fracturing, a behavior similar to that exhibited by most metals under tensile or bending stresses. Because of this capability, HPFRCCs are more resistant to cracking and last considerably longer than normal concrete. Another extremely desirable property of HPFRCCs is their low density. A less dense, and hence lighter material means that HPFRCCs could eventually require much less energy to produce and handle, deeming them a more economic building material. Because of HPFRCCs' lightweight composition and ability to strain harden, it has been proposed that they could eventually become a more durable and efficient alternative to typical concrete.

HPFRCCs are simply a subcategory of ductile fiber-reinforced cementititous composites (DFRCCs) that possess the ability to strain harden under both bending and tensile loads, not to be confused with other DFRCCs that only strain harden under bending loads.

Composition

Because several specific formulas are included in the HPFRCC class, their physical compositions vary considerably. However, most HPFRCCs include at least the following ingredients: fine aggregates, a superplasticizer, polymeric or metallic fibers, cement, and water. Thus the principal difference between HPFRCC and typical concrete composition lies in HPFRCCs' lack of coarse aggregates. Typically, a fine aggregate such as silica sand is used in HPFRCCs.

Material properties

Strain hardening, the most coveted capability of HPFRCCs, occurs when a material is loaded past its elastic limit and begins to deform plastically. This stretching or 'straining' action actually strengthens the material. This phenomenon is made possible through the development of multiple microscopic cracks, opposed to the single crack/strain softening behavior exhibited by typical fiber-reinforced concretes. It occurs in HPFRCCs as several fibers slip past one another.

One aspect of HPFRCC design involves preventing crack propagation, or the tendency of a crack to increase in length, ultimately leading to material fracture. This occurrence is hindered by the presence of fiber bridging, a property that most HPFRCCs are specifically designed to possess. Fiber bridging is the act of several fibers exerting a force across the width of a crack in an attempt to prevent the crack from developing further. This capability is what gives bendable concrete its ductile properties.

Design methodology

The basis for the engineered design of different HPFRCCs varies considerably despite their similar compositions. For instance, the design of one type of HPFRCC called ECC stems from the principles of micromechanics. This field of study is best described as relating macroscopic mechanical properties to a composite's microstructure, and is only one specific method used to design HPFRCCs. Another design methodology used in other formulas of HPFRCCs is based on the material's ability to withstand seismic loading.

Applications

Proposed uses for HPFRCCs include bridge decks, concrete pipes, roads, structures subjected to seismic and non-seismic loads, and other applications where a lightweight, strong and durable building material is desired.

Though HPFRCCs have been tested extensively in the lab and been employed in a few commercial building projects, further long-term research and real-world application is needed to prove the true benefits of this material.

Epoxy resin screeds and self-smoothers are hard wearing resin systems which can provide properties such as chemical resistance, slip resistant and hygienic finishes. Decorative finishes can also be achieved by adding coloured flakes or aggregates.

Epoxy Resins and screeds

Epoxy resin screeds and self-smoothers are hard wearing resin systems which can provide properties such as chemical resistance, slip resistant and hygienic finishes. Decorative finishes can also be achieved by adding coloured flakes or aggregates.

Epoxy resin systems are ideal for heavy duty industrial areas as well as food environments and other areas where cleanliness is key.

Resuflor is a self-smoothing, epoxy resin seamless floor finish, combining outstanding wearing properties with chemical resistance and a decorative finish. Resuflor is available in a range of colours and is ideally suited to areas where jointed finishes (tile, sheet) are not acceptable and where maximum cleanliness is essential. Additional decorative effects can be produced by the introduction of coloured plastic flakes, lightly scattered on the surface and sealed.

An anti-slip finish can be created by applying one coat of Resutop or Resucoat HB to the cured surface, and then scattering a fine aggregate onto the surface whilst wet. This can then be sealed with a top coat of Resutop or Resucoat HB. Resutile or Resutop LV is recommended as a top coat in areas where very high chemical resistance is required. Please use the free RSL specification service for more information.

Product Benefits:

- Seamless
- Easy to clean & maintain (do not steam clean or use hot water above 60'C)
- Chemical resistance
- Hard-wearing
- Decorative
- Hygienic; does not support fungus or bacterial growth
- Non-Dusting

- Available in a range of attractive colours

Where to use:

Resuflor is ideal for areas where maximum cleanliness and durability is paramount, including food processing, laboratories, clean rooms, operating theatres and general light industry.

Resuscreed 43 is a heavy duty, epoxy resin floor screed, with high chemical resistance and strong colour definition. Sealing is necessary where impervious finishes are required. Resuscreed 43 is normally laid from 4-6mm nominal thickness.

Product Benefits:

- Low odour
- Hard wearing
- Durable
- Easy to apply and work to achieve good quality smooth surfaces
- Suitable for localised repairs prior to resurfacing
- Decorative
- Good slip-resistance
- Abrasion resistant
- Impact resistant
- Non-Dusting
- Can be feather-edged

Where to use:

Resuscreed 43 is ideal for heavy duty industrial applications including engineering and chemical production, food production and preparation, automotive and hygiene conscious environments.

Resuscreed 50

Resuscreed 50 is a general purpose, epoxy resin screed, with good wearing properties and strong colour definition.

Resuscreed 50 is a three component epoxy resin screed comprising base resin, hardener, and two bags of aggregate. Surface sealing with R.S. Screed Seal Coating is recommended.

Product Benefits:

- Hard wearing
- Durable
- Easy to apply and work to achieve a good quality smooth surface
- Suitable for localised repairs prior to resurfacing
- Decorative
- Abrasion resistant
- Impact resistant

Where to use:

Resuscreed 50 is ideal for light to medium duty industrial applications including engineering, warehouses, fork truck lanes and aerospace environments; where good abrasion resistance is required.

RSL also produce a proven range of Maintenance products to repair existing subfloors and to use sealants for joints.

All of our maintenance products adhere well to most surfaces and are easy to use with long life expectancies.

Resupatch is an easy to use epoxy Resin Mortar which has exceptional adhesive properties. This makes it ideal for rapid repair of concrete surfaces in heavy duty environments

Resupatch is non-dusting and highly resistant to damage by abrasion, chemicals, water or oil.

Product Benefits:

- Minimum surface preparation
- Easy to use
- Cures rapidly
- Bonds to concrete, steel, wood or stone
- Concrete-like in appearance
- Dust-free and permanent
- Impact Resistant

Where to Use:

Resupatch is designed for general application as a concrete repair compound, especially for filling in wide cracks and holes in concrete floors, broken steps, walls and other concrete surfaces. It can also be used on worn floors and inclines.

Self-Compacting Concrete (SCC):

Defined by researchers as: “concrete that is able to flow and consolidate under its own weight, completely fill the formwork of any shape, even in the presence of dense reinforcement, while maintaining homogeneity and without the need for any additional compaction”

Origin

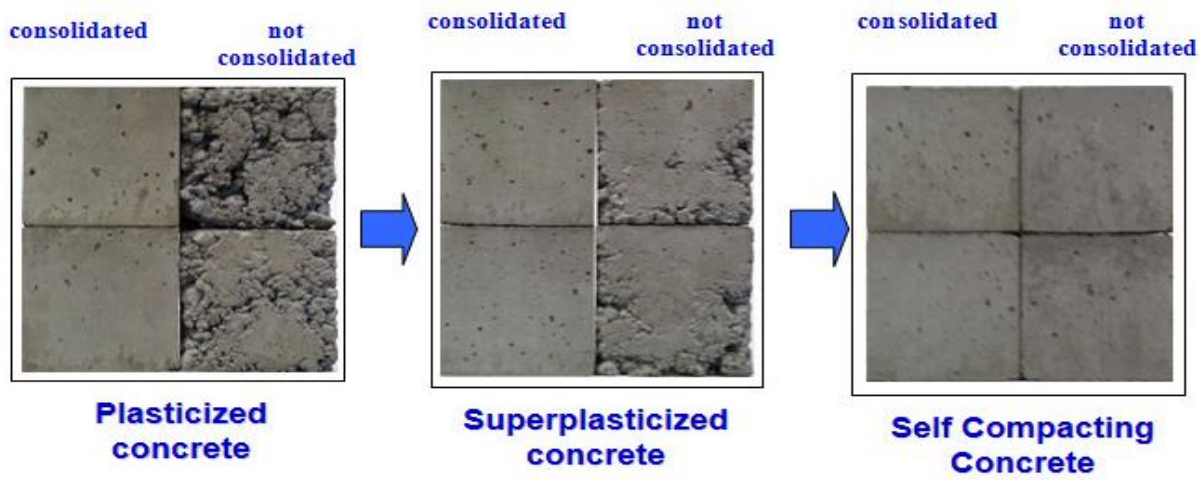
- Introduced to the concrete industry, in Japan, primarily, through the work of Professor Okamura in the late 1980’s.
- Motivation behind this was the gradual reduction of skilled labor, which led to the reduction in the quality of construction work, affecting adversely, the durability of concrete due to poor compaction.

MATERIALS

SELF-COMPACTING CONCRETE

- SCC has more powder content and less coarse aggregate
- Fillers used can be flyash, ground granulated blast furnace slag, condensed silica fume, rice husk ash, lime powder, chalk powder & quarry dust
- SCC incorporates high range water reducers (HRWR, Superplasticizers) & frequently, viscosity modifying agent in small amount.

From traditional concrete to SCC



Potential Benefits of SCC

Contractor

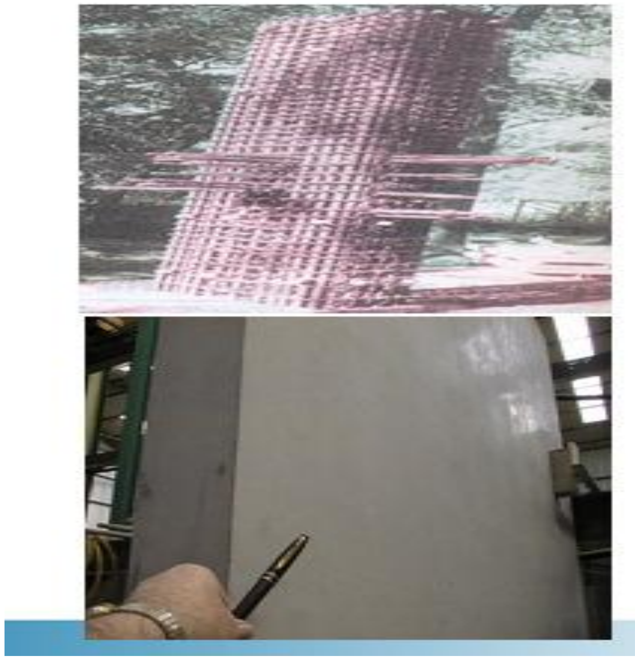
• Reduced labor requirement & cost

• Reduced plant requirement

• Reduced remedial work

• Reduced noise, improved site health & safety

• No vibrating equipment required, Reduces placing costs



Designer / client

• Use in more complex design & heavy reinforcement

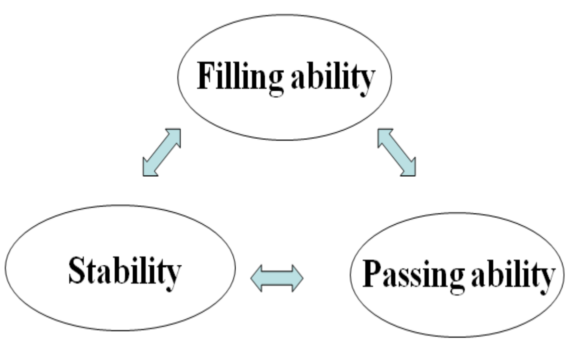
• Improved aesthetics & durability

• Quicker construction time

• Less variation in the production of concrete & more homogeneous concrete

• Better surface finish

FRESH SCC REQUIREMENTS



Fresh SCC Properties

Filling ability

“The ability of SCC to flow into and fill completely all spaces within the formwork, under its own weight.”

Fresh SCC Properties

Passing ability

“The ability of SCC to flow through tight openings such as spaces between steel reinforcing bars without segregation or blocking

“The ability of SCC to remain homogeneous in composition during transport and placing.”

Segregation resistance

CHARACTERSTICS OF SCC

- If SCC should not segregate- it must have mortar rich in fines & is also able to transport the coarse aggregate & keep them in viscous suspension
- Cement cannot be the only finer/filler material
- Mineral admixtures are used to enhance the deformability & stability of concrete

- Chemical admixtures are a must for achieving excellent flow at low water content. VMA reduces bleeding & improves the stability of the concrete mixture
- Compared to Conventional Concrete, SCC has Higher powder content in the order of 450-600 Kg/m3
- Lower water/cement ratio. Typical range of water is 160 to 185 kg/ m3 & water/binder ratio, by volume in the range of 0.7 to 1.25. Volume of paste 0.36 to 0.43
- Lower coarse/fine aggregate ratio
- Use of superplasticizers & VMA compatible with cement in small percentages.

TEST METHODS FOR DETERMINIG FRESH SCC PROPERTIES

FILLING ABILITY

- Slump flow & T

  50CM slump flow

- V- Funnel

PASSING ABILITY

- L-Box
- U-box
- J-ring
- Fill Box

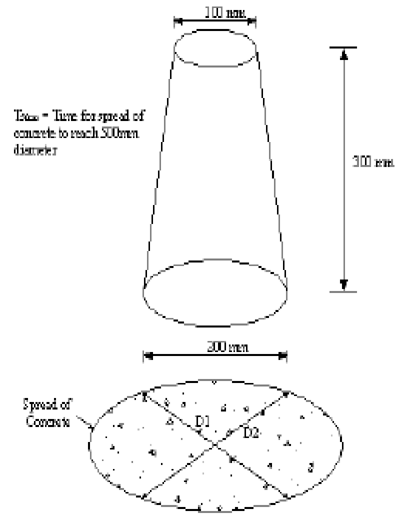
SEGREGATION RESISTANCE

- V-Funnel at T5 Minutes
- GTM Screen stability test

- SEGREGATION RESISTANCE
    - V-Funnel at $T_{5\ \text{Minutes}}$
    - GTM Screen stability test

Slump flow (spread)

- Most popular method
- Assess the horizontal free flow of concrete in th
- Measures the filling ability
- Normal range of flow recommended
    - 650 mm to 800 mm



Slump flow (spread)

- Secondary measurement of T50 cm can be made
- Represents time taken in seconds to reach horizontal diameter of 500 mm
- Recommended limits are-2sec to 5sec

V-Funnel Test

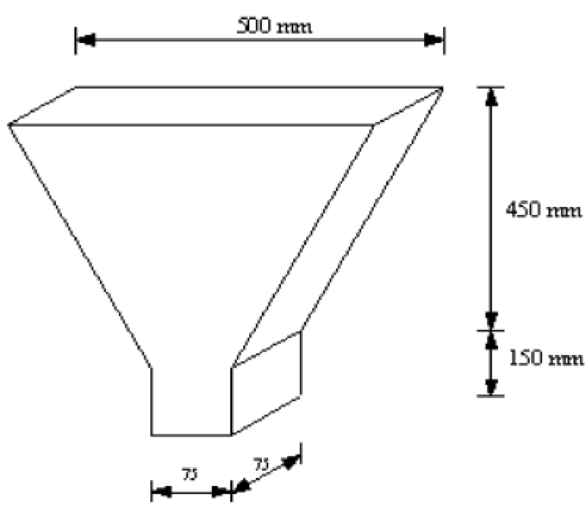
- To assess the flowability of fresh concrete
- The time taken for concrete to flow through the narrow end is measured
- Measures viscosity of concrete

V-Funnel Test

- Recommended value for V-funnel flow
- < 12sec

V-Funnel Test

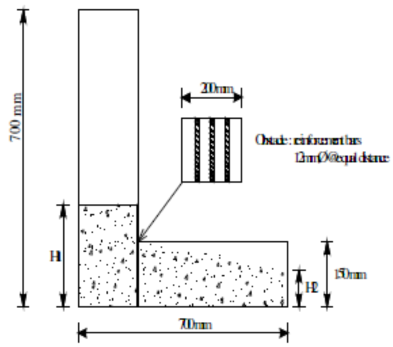
- To assess the flowability of fresh concrete
- The time taken for concrete to flow through the narrow end is measured
- Measures viscosity of concrete



TEST METHODS

L-Box Test

- Passing ability of fresh concrete.
- T 20 cm and T 40 cm marks of horizontal section of L – box are the indications of ease of flow of concrete.
- Recommended values of flow time are :
    - T 20 cm = 1 ± 0.5 sec
    - T 40 cm = 2 ± 0.5 sec



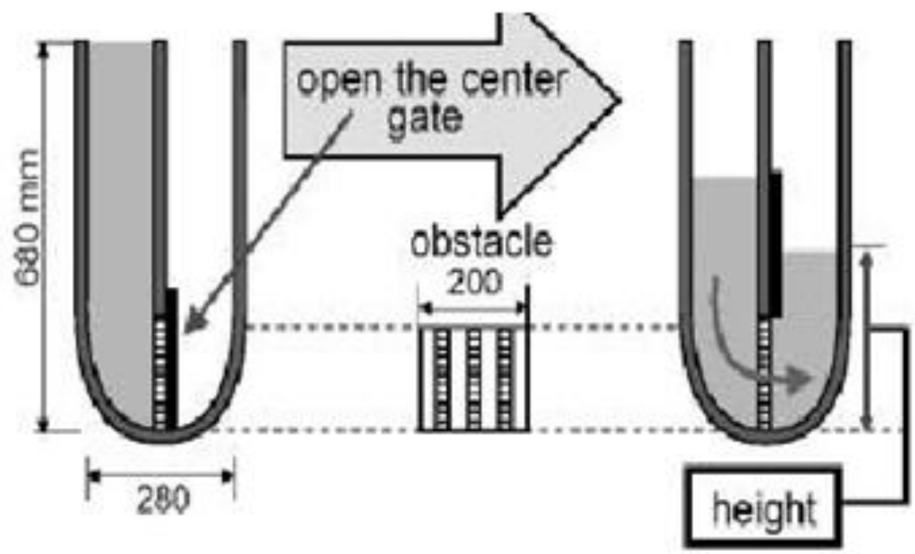
L-Box Test

- Height of the concrete at the end of the horizontal section is expressed as a proportion of that of remaining in the vertical section (H2/H1).
- Recommended value for blocking ratio:
    - Blocking ratio H2/H1 ≥ 0.80.

U-Box Test

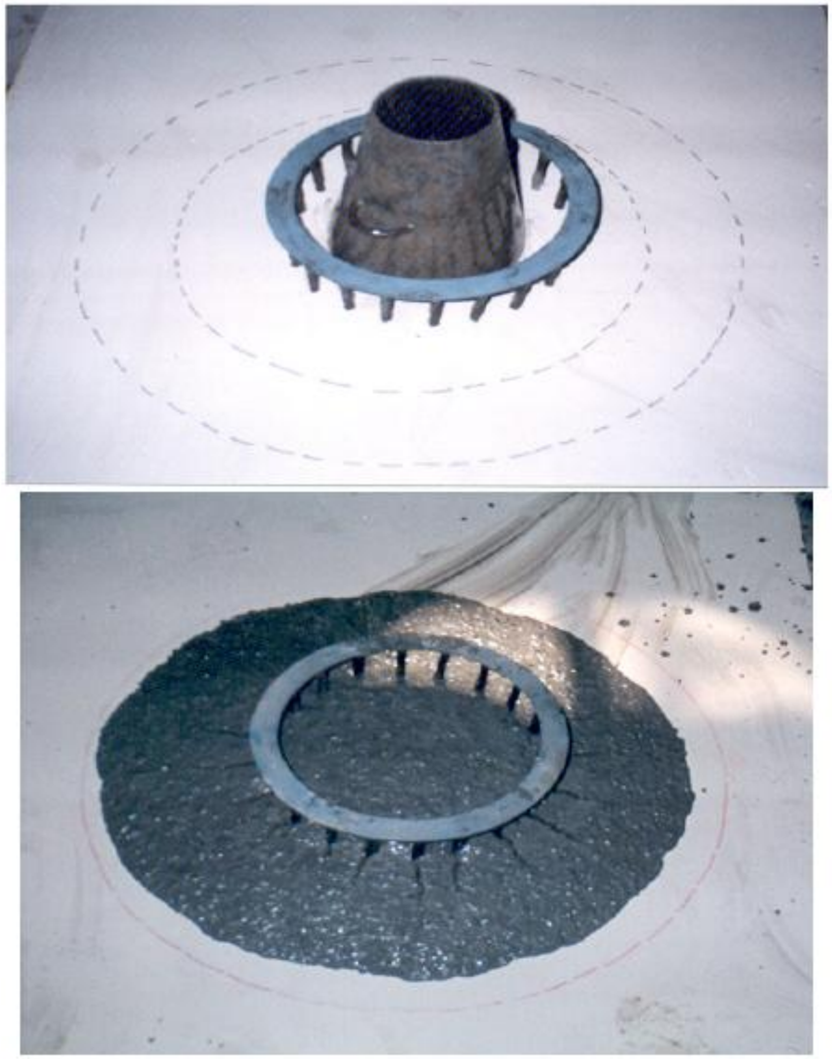
- Also called as ‘Box-shaped’
- Measures the filling ability of concrete.
- The difference in height of two sections is measured.
- Recommended value:

0 difference in the height of the limbs < 30 mm



J-Ring Test

- Measures passing ability of concrete
- Can be used in conjunction with Slump flow test, combination can test filling ability & passing ability
- The difference in height, in between the concrete inside and that just outside the J-ring is measured
- Difference in height of maximum of 10 mm is considered appropriate



J-ring Test

- Simple test.
- Bars can be of different diameters and also varied spacing:
- 0 Preferably three times the maximum aggregate size
- Used in conjunction with slump flow test
- V5min flow time
- This is secondary parameter of the V-funnel test
- Measures time of flow of concrete after time gap of 5min
- Indicates the tendency for segregation
- Recommended value is:

0 < +3 sec of time at zero hours

Acceptance of SCC

Combinations may be-

- Slump flow , V-funnel and U-box tests (Japan)
- Slump flow and L-Box (Sweden)
- J-ring and U-box

Slump flow, U-Box/L-Box, V-funnel (at 5min.)

Characteristics of SCC in Hardened state

Typical Properties of hardened SCC

Typical Properties of hardened SCC

Items	SCC
Water-binder ratio(%)	25 to 40
Compressive strength (age: 28 days) (MPa)	40 to 80
Compressive strength (age:91 days) (MPa)	55 to 100
Splitting tensile strength (age: 28 days) (MPa)	2.4 to 4.8
Elastic modulus (GPa)	30 to 36
Shrinkage strain ($x10^{-6}$)	600 to 800

APPLICATIONS OF SELF COMPACTING CONCRETE IN JAPAN

Osaka Gas Station

First Application of SCC (1997-1998)

Akashi-Kaikyo

Summary

- One of the outcomes of using High Strength Concrete is slender members and Consequently, very dense reinforcement. Normal methods of vibration are not effective, Hence SCC.
- SCC has various other applications. It is especially suited to pre-cast/prefab products. In Japan, they now use for casting composite columns, steel tubes with shear lugs inside filled with SCC and no other reinforcement. Very tall columns have been made.
- Very few national standards exists as of now for SCC (Japan, Europe, Italy etc.,)
- SCC mixes are very sensitive to variation in water.
- Water curing is absolutely necessary for 3 to 7 days.
- SCC should be treated as high quality concrete and not meant for low strength applications
- SCC can be advantageously used for all types of work with proper understanding
- of itsbehavior
- It is a matter of time SCC replacing Normal Concrete even in INDIA

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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

UNIT – V – ADVANCED CONCRETE TECHNOLOGY– SCIA7001

UNIT 5

CONCRETING METHODS

Process of manufacturing of concrete, methods of transportation, placing and curing. Extreme weather concreting, special concreting methods. Vacuum dewatering - underwater concrete, special form work.

Process of Manufacture of Concrete

- It is interesting to note that the ingredients of good concrete and bad concrete are the same.
- If meticulous care is not exercised, and good rules are not observed, the resultant concrete is going to be of bad quality.
- With the same material if intense care is taken to exercise control at every stage, it will result in good concrete.
- The various stages of manufacture of concrete are:

(a) Batching (b) Mixing (c) Transporting (d) Placing (e) Compacting (f) Curing (g) Finishing

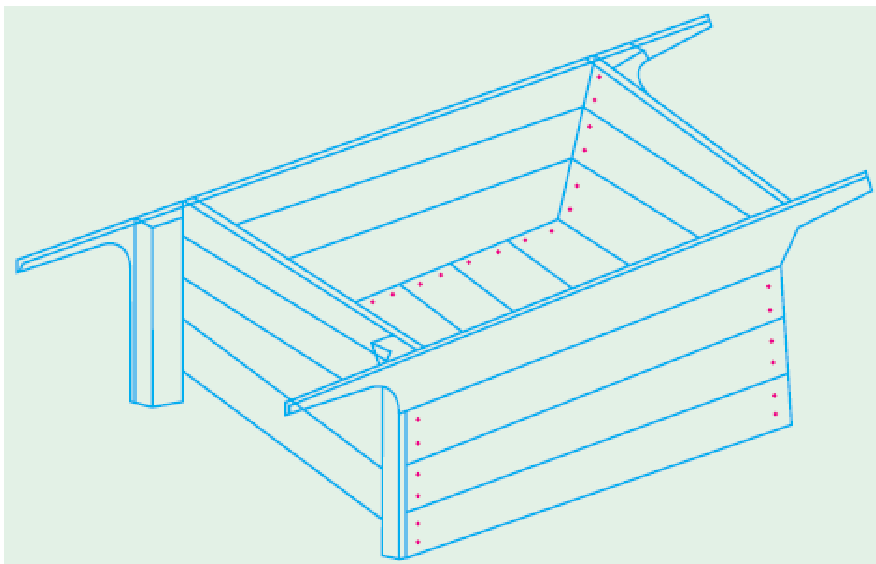
Batching:

1. Volume Batching:

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

Batching:

1. Volume batching: Materials can be measured by using gauge box or measuring box, usually it is made of steel or wooden lanks.



Gauge Box

Batching : Volume Batching

Table 6.3. Volume of Various gauge boxes

Item	*Width cm*	*Height cm*	*Depth cm*	*Volume litres*	*Quantity number*
A	33.3	30	20	20	1
B	33.3	30	25	25	2
C	33.3	30	30	30	2
D	33.3	30	35	35	2

Table 6.4 Batch volume of materials for various mixes

	Cement kg.	*Sand, litres*	*Coarse aggregate, litres*
1 : 1 : 2 (M 200)	50	35	70
1 : 1 1/2 : 3 (M 200)	50	52.5	105
1 : 2 : 3	50	70	105
1 : 2 : 4 (M 150)	50	70	140
1 : 2 1/2 : 5	50	87.5	175
1 : 3 : 6 (M 100)	50	105	210

2. Weigh Batching:

- Weigh batching is the correct method of measuring the materials.
- Use of weight system in batching, facilitates accuracy, flexibility and simplicity.
- Large weigh batching plants have automatic weighing equipment.
- On large work sites, the weigh bucket type of weighing equipment's are used.

Batching: Weigh Batching equipments

DESCRIPTION OF WORK	GRADE OF CONCRETE
Concrete in columns, beams	1:1:2
Water retaining structures, Piles, precast work or dense Concrete.	1:1.5:3
RCC beams, slabs, columns	1:2:4
Foundations for buildings, Mass reinforced works.	1:3:6
For mass concrete work.	1:4:8

WATER CEMENT RATIO

- In the preparation of concrete the water cement ratio is very important
- For normal construction the water cement ratio is usually 0.5
- Adding to much water will reduce the strength of concrete and can cause seggregation.

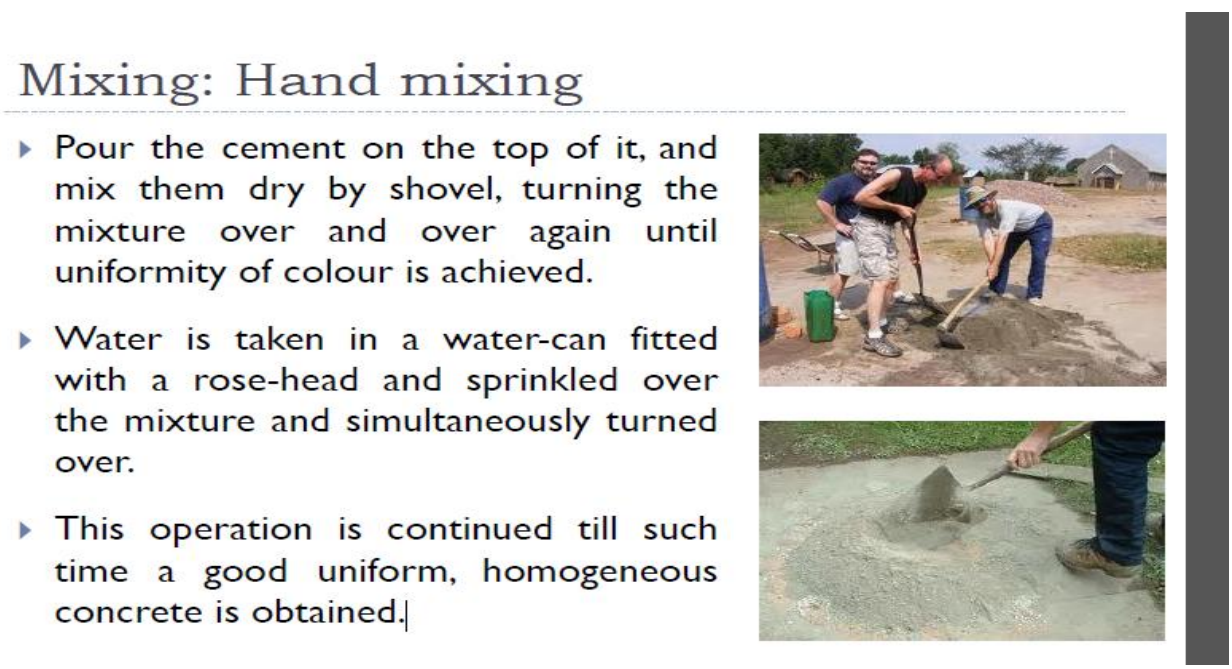
Mixing

- Thorough mixing of the materials is essential for the production of uniform concrete.
- The mixing should ensure that the mass becomes homogeneous, uniform in colour and consistency.
- There are two methods adopted for mixing concrete:

(i) Hand mixing (ii) Machine mixing

Mixing: Hand mixing

- Hand mixing is practiced for small scale unimportant concrete works.
- As the mixing cannot be thorough and efficient, it is desirable to add 10 per cent more cement to cater for the inferior concrete produced by this method.
- Hand mixing should be done over an impervious concrete or brick floor of sufficiently large size to take one bag of cement.
- Spread out the measured quantity of coarse aggregate and fine aggregate in **alternate layers.**



Mixing: Machine Mixing

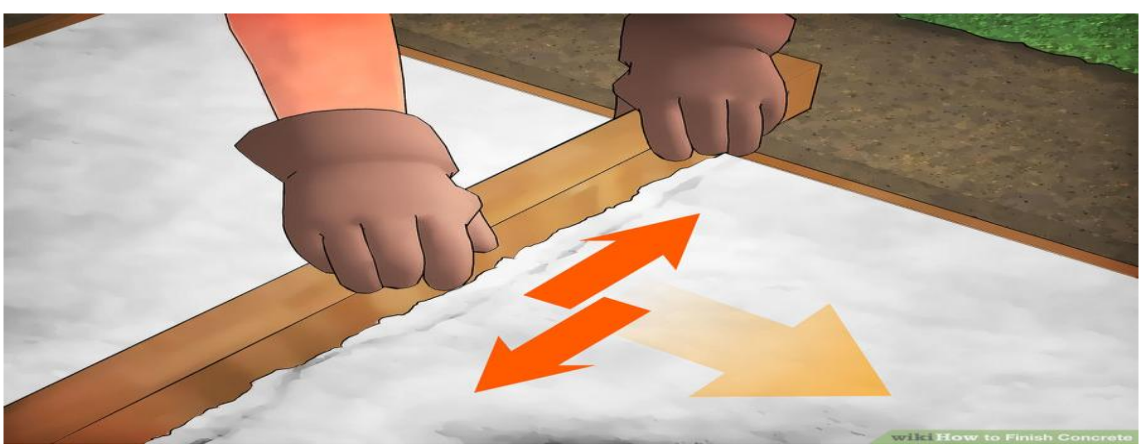
- Mixing of concrete is almost invariably carried out by machine, for reinforced concrete work and for medium or large scale mass concrete work.
- Machine mixing is not only efficient, but also economical, when the quantity of concrete to be produced is large.
- They can be classified as batch-mixers and continuous mixers.
- Batch mixers produce concrete, batch by batch with time interval, whereas continuous mixers produce concrete continuously without stoppage till such time the plant is working.
- In normal concrete work, it is the batch mixers that are used. Batch mixer may be of pan type or drum type.
- The drum type may be further classified as tilting, non-tilting, reversing or forced action type.
- As per I.S. 1791–1985, concrete mixers are designated by a number representing its nominal mixed batch capacity in litres. The following are the standardized sizes of three types:

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

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

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

PLACING:


wikiHow to Finish Concrete

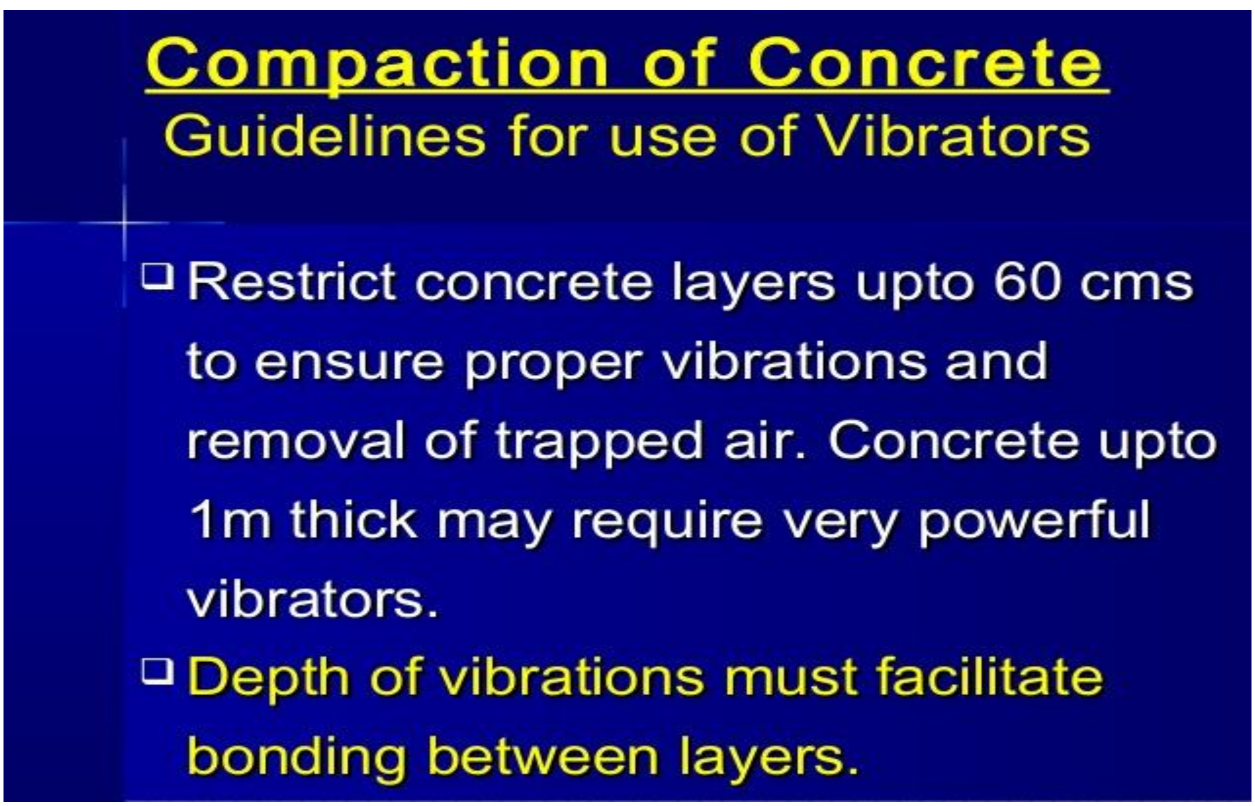
COMPACTION OF CONCRETE

Purpose of compaction is that to pull out air from void and make concrete harden.
Compaction done by-
1.Mechanically surface vibrator

2. Manually hand tempers

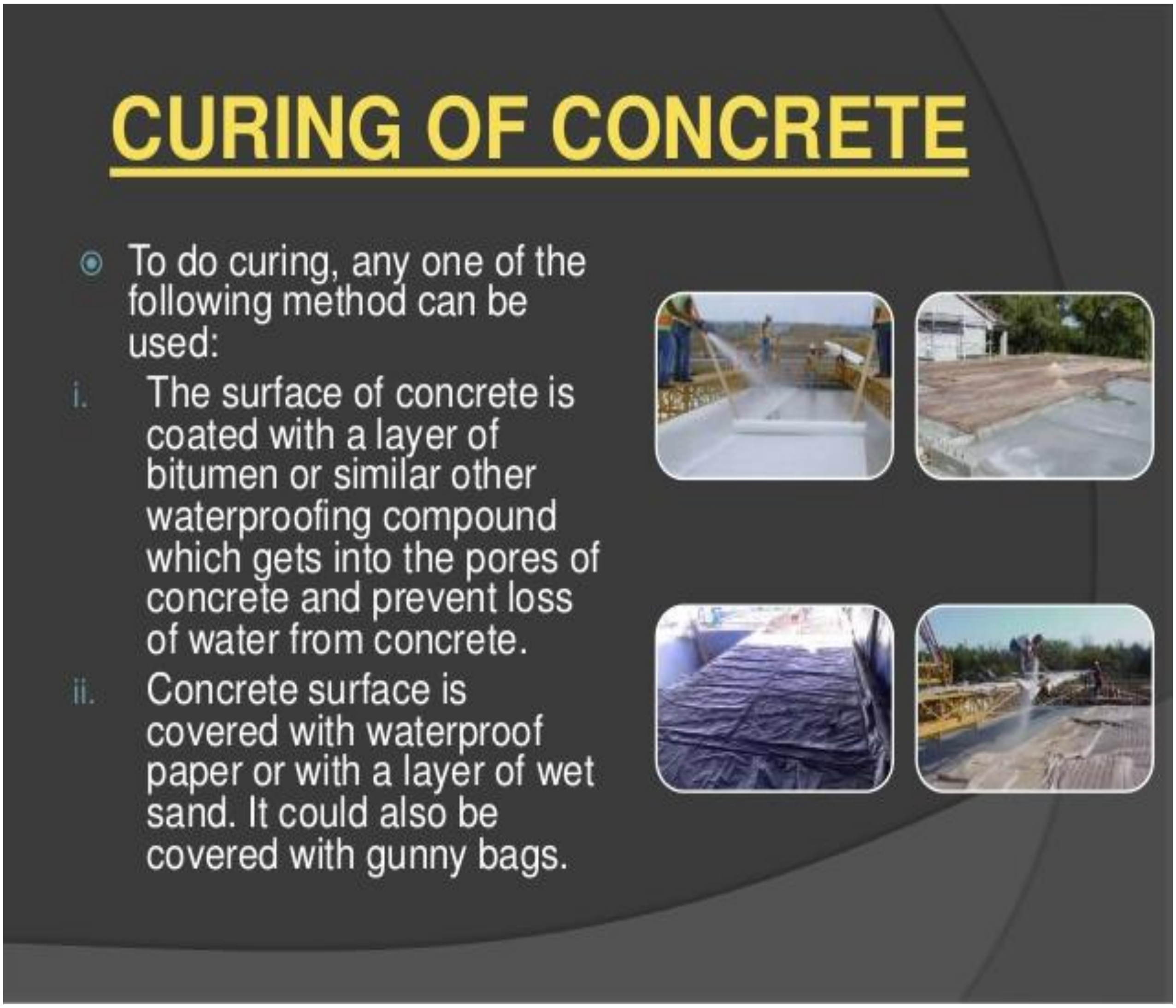
➢ After this, **Floating, Belting, Screeding or strike off, Bull floating and Brooming** is done as per requirement for the finishing purpose of concrete pavement to smoothen the top surface.

Needle Vibrator



MODEL NO.		BP-S80H	BP-S80L	BP-S80R	BP-S80D	Picture for Reference
Operating Mass	KG	75	75	75	75	
Trowel Diameter	mm	780	780	780	780	
Gurad Diameter	mm	800	800	800	800	
Nubmer of Blade	PCS	4	4	4	4	
Speed Range	r/min	60-100	60-100	60-100	60-100	
Pitch Range		1-15	1-15	1-15	1-15	
Engine Type		Gasoline	Gasoline	Gasoline	Diesel	
Engine Brand		Honda	Loncin	Robin	Power-Gen	
Engine Model		GX160	200F	EY20	BD170F	
Max. Power	HP	5.5	6.5	5	4.2	
Packing Size	mm	1120*890*850				

FINISHING



EXTREME WEATHER CONCRETING

In countries which experience extreme weather conditions special problems are encountered in preparation, placement and curing of concrete. India has regions of extreme hot weather (hot-humid and hot-arid) as well as cold weather. The Indian Standards dealing with extreme weather concreting are: IS: 7861 (Part 1-1975 Reaff. 2007)-Hot weather concreting and IS: 7861 (Part 2-1981 Reaff. 2007) -Cold weather concreting.

HOT WEATHER CONCRETING:

Special problems are encountered in the preparation, placement and curing of concrete in hot weather. High temperatures result in:

- Rapid hydration of cement
- Increased evaporation of mixing water
- Greater mixing water demand
- Large volume changes in concrete resulting in cracks.
- Reduction in strength.

The climatic factors affecting concrete in hot weather are:

1. High ambient temperature
2. Reduced relative humidity
3. Increased wind velocity

Problems associated with hot weather concreting shall be addressed as follows:

1. controlling the temperature of concrete ingredients
2. Suitable proportioning of concrete mixes.
3. Controlling the temperature of concrete as placed.
4. Controlling the processes such as concrete production and delivery
5. Carrying out effective protection and curing of placed concrete.

Controlling the temperature of concrete ingredients:

The most direct approach to keep concrete temperature down is by controlling the temperature of its ingredients. The contribution of each ingredient to the temperature of concrete is a function of the temperature, specific heat and quantity used of that ingredient. The aggregates and mixing water exert the most pronounced effect on temperature of concrete. Thus, in hot weather all available means shall be used for maintaining these materials at as low temperatures as practicable.

Aggregates

Any one of the procedures or a combination of the procedures given below may be used for lowering the temperature or at least for preventing excessive heating of aggregates.

Shading stockpiles from direct rays of the sun.

Sprinkling the stockpiles of coarse aggregate with water and keeping them moist.
This results in cooling by evaporation, and this procedure is specially effective when relative humidity is low. Such sprinkling should not be done haphazardly because it leads to excessive variation in surface moisture and thereby impairs uniformity of workability. When coarse aggregates are stockpiled during hot weather, successive layers should be sprinkled as the stockpile is-built up. If cold water is available, heavy spraying of coarse aggregate immediately before use may also be done to have a direct cooling action. Coarse aggregates may also be cooled by methods, such as inundating them in cold water or by circulating refrigerated air through pipes or by other suitable methods.

Water

Efforts shall be made to obtain cold water, and to keep it cold by protecting pipes, water storage tanks, etc. Tanks or trucks used for transporting water shall be insulated and/or coloured and maintained white or yellow the mixing water has the greatest effect on temperature of concrete, since it has a specific heat of about 4.5 to 5 times that of cement or aggregate. The temperature of water is easier to control than that of other ingredients and, even though water is used in smaller quantities than the other ingredients, the use of cold mixing water will effect a moderate reduction in concrete placing temperatures. For a nominal concrete mixture containing 336 kg of cement, 170 kg water, 1850 kg of aggregate per ma, a change in 2°C water temperature will effect a 0.5 º C change in the concrete temperature.

Under certain circumstances, reduction in water temperature may be most economically accomplished by mechanical' refrigerator or mixing with crushed ice. Use of ice as a part of the mixing water is highly effective in reducing concrete temperature since, on melting alone, it takes up heat at the rate of 80 kcal/kg. To take advantage of heat of fusion, the ice shall be incorporated directly into the concrete as part of the mixing water. Conditions shall be such that the ice is completely melted by the time mixing is completed.

NOTE :- If the ice is not melted completely by the time mixing is completed, there can be a possibility of Ice melting after consolidation of concrete and thus leaving hollow pockets in concrete, with detrimental effects.

Recommended procedure for concreting during hot weather conditions is given below:

Ambient temperature shall be below 40degree Celsius at the time of placement of concrete. Concreting may be planned during morning and evening hours.
The period between mixing and delivery (placing) shall be kept an absolute minimum.

Keep aggregates under shade and cool aggregates by sprinkling water.
Formwork, reinforcement shall be sprinkled with cool water just prior to placement of concrete.

COLD WEATHER CONCRETING:

The production of concrete in cold weather introduces special and peculiar problems which do not arise while concreting at normal temperatures. Quite apart from the problems associated with setting and hardening of cement concrete, severe damage may occur if concrete which is still in the plastic state is exposed to low temperature, thus causing ice lenses to form and expansion to occur within the pore structure. Hence it is essential to keep the temperature of the concrete above a minimum value before it is placed in the formwork. After placing, concrete may be kept above a certain temperature with the help of proper insulating methods before the protection is removed. During periods of low ambient temperature, special techniques are to be adopted to cure the concrete while it is in the formwork or after its removal.

The Precautions to be taken and methods adopted for concreting in sub-zero temperature is listed below.

a. Utilization of the heat developed by the hydration of cement and practical methods of insulation.
b. Selection of suitable type of cement
c. Economical heating of materials of concrete

(Heating of water is the easiest to be adopted)

d. Admixtures of anti-freezing materials
e. Electrical heating of concrete mass

VACUUM DEWATERING SYSTEM

A high quality concrete floor or pavement requires not only being level but it should also have high wear resistance, high compressive strength, reduced shrinkage and minimum water permeability.

THE CONCEPT

The TREMIX method, pioneered by TREMIX AB, SWEDEN and introduced by

Aquarius in India in 1987 is system for laying high quality concrete floors with superior cost-effectiveness. Aquarius subsequently entered into a technical collaboration with TREMIX AB, in 1991 to start production of Vacuum System in India. The key to the use of this method is the dewatering of concrete by vacuum process. Surplus water from the concrete is removed immediately after placing and vibration, reducing the water: cement ratio to an optimum level. Therefore, adopting the TREMIX method facilitates use of concrete with better work ability than what is normally possible

A lowered water: cement ratio automatically leads to a noticeable improvement in almost each of the concrete properties.

THE OPERATION

In order to obtain a high quality concrete floor using this method, it is essential to follow the various operations in the correct sequence. Initially, poker vibration is essential, especially at the panel edges. This results in proper compaction of the concrete and hence elimination of voids and entrapped air. Poker vibration never really gives a levelled surface. It is therefore essential to combine this vibration with surface vibration (screeding), in order to obtain a vibrated concrete with a levelled surface. Two passes with surface vibrator are normally recommended. The Surface Vibrator is guided by two men, standing on either side of the panel.

Vacuum dewatering process removes surplus water always present in the concrete. This is done using the Vacuum Equipment comprising of Suction Mat Top Cover, Filter pads and Vacuum Pump.

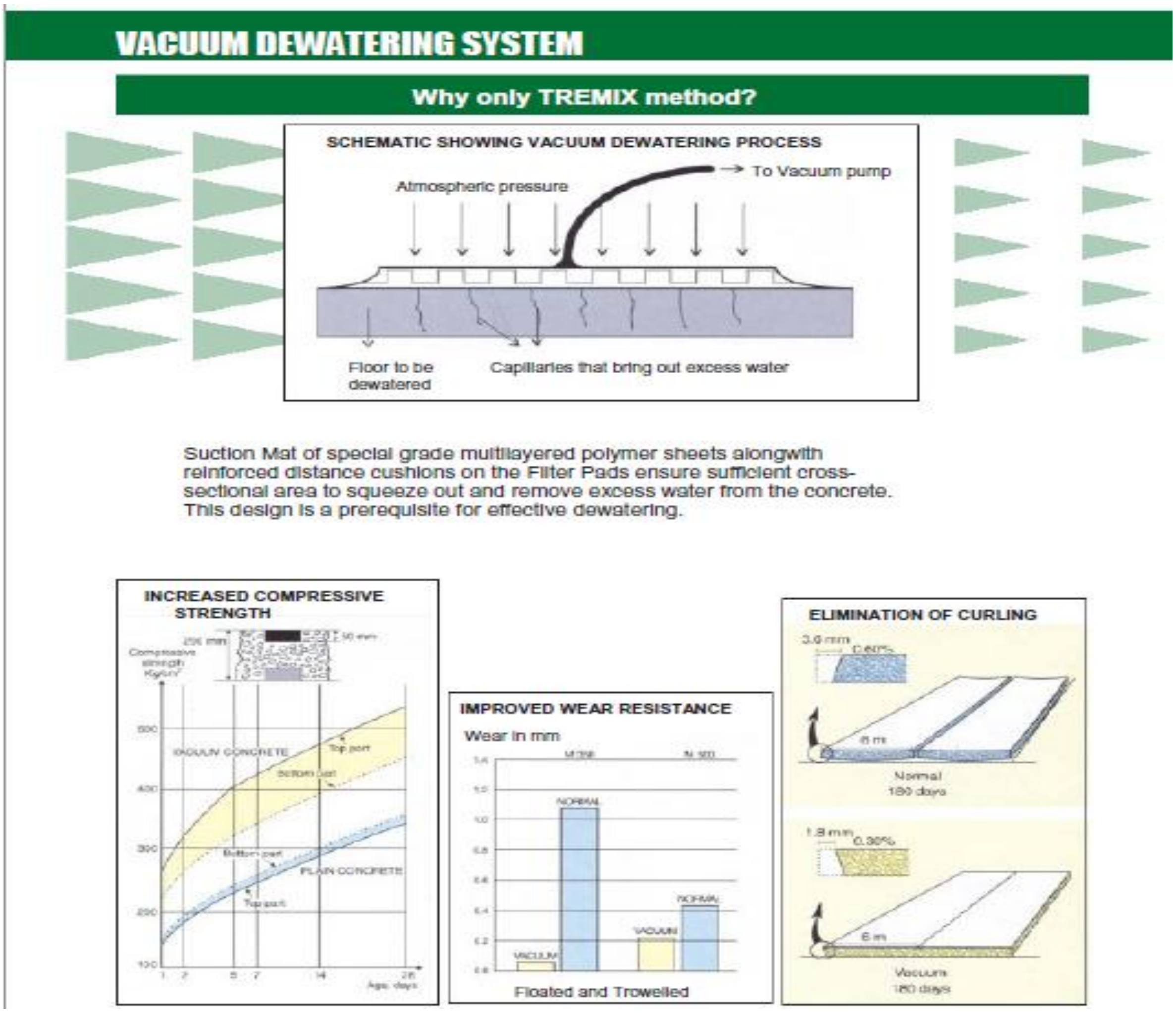
The process starts immediately after surface vibration. Filter pads are placed on the fresh concrete leaving about 4 inches of fresh concrete exposed on all sides. The Top Cover is then placed on the filter pads and rolled out till it covers the strips of exposed concrete on all sides.

The Top Cover is then connected to the vacuum pump through a suction hose and the pump is started.

Vacuum is immediately created between the filter pads and the top cover. Atmospheric pressure compresses the concrete and the surplus water is squeezed out. This process lowers the water content in the concrete by 15-25%.

The dewatering operation takes approx.1.5 - 2 minutes per centimeter thickness of the floor. The dewatered concrete is compacted and dried to such an extent that it is possible to walk on it without leaving any foot prints. This is the indication of concrete being properly dewatered and ready for finishing.

The finishing operations - Floating & Trowelling take place right after dewatering. Floating operation is done with Floating disc. This ensures after mixing of sand & cement particles, further compaction and closing the pores on the surface. Floating operation generates skid-free finish. Trowelling is done with Trowelling blades in order to further improve the wear resistance, minimize dusting and obtain smoother finish. Repeated passes with disc and blades improve the wear resistance substantially.



UNDERWATER CONCRETE

f. Use of air-entraining agents.

g. Concrete is the premier construction material across the world and the most widely used in all types of civil engineering works.

h. During the construction of bridges , dams or any other structure where the foundation part of the structure is lie underwater, we have to opt for underwater construction

i. When concrete is placed under water, it induces concrete to deteriorate uniformity

j. Therefore should be follow proper mix design, concrete production and placement and quality control.

PRODUCTION OF UNDER WATER CONCRETE

Proper mix design

- Proportioning underwater concrete are same as conventional concrete
- According to its performance there are two classes of concrete mixture
- standard mixture
- high-performance mixture
- Concrete placed underwater is susceptible to
- cement washout
- laitance
- Segregation
- Mix design influence certain workability characteristics such as
- Flowability
- Self-consolidation
- Cohesion
- Mix design also influence by rheology
- It describes flow and deformation of materials
- The behaviour of fresh concrete can be described by two parameters-yield stress and

plastic viscosity

- water content is the important factor affecting the rheology of concrete
- water content in a mixture can be classified into two categories
- water absorbed in the aggregate
- free water
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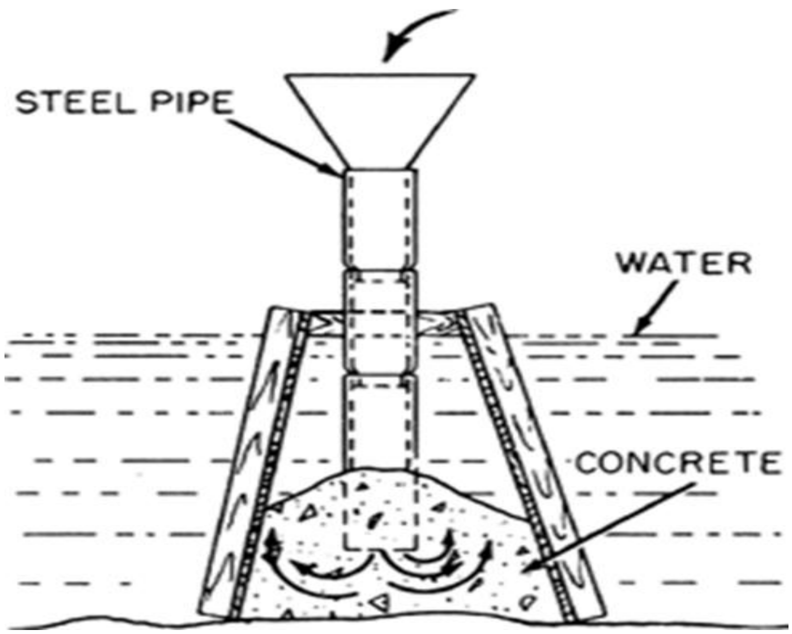
PLACEMENT METHODS

- Tremie method.
- Pump method
- Toggle bags
- Bags work.

Laying of concrete by using Tremie



TOGGLE BAGS

- Toggle bags are ideal for small amounts of concrete placement.
- The bag is filled in the dry with wet concrete
- Used for repair work.
- The concrete is squeezed out by a diver.

BAGWORK

- Bags are made of open weave material.

Diver-handled bags are usually of 10 to 20 litres capacity but 1cub.m bags can be placed using a crane

Concrete production

- The standard requirements of underwater concrete is same as conventional concrete
- Production and delivery system be capable of producing concrete at the required placement rate
- It is essential that the materials can be supplied to the batch plant at the required rate

- The logistical planning should include
    - Provision for alternative supplies
    - Provision of all the accessory items

CONSTRUCTION TECHNIQUES

Caissons

- Watertight retaining structure .
- Permanent in nature.
- Used to work on foundation of bridge pier, construction of concrete dam or for the repair of ships.
- Constructed in such a manner so that the water can be pumped out.
- Keeps working environment dry.
- **Box caisson**
- Pre fabricated concrete box, it is set down on the prepared bases
- Once in place it is filled with concrete as part of placement work
- Must be ballasted or anchored to prevent this phenomenon the floating of hollow concrete structures
- **Open caisson**
- similar to a box caisson but does not have bottom face
- Used in soft clays not having large obstructions beneath
- During sinking it may filled with water
- **Compressed-air caisson**
- It has the advantage of providing dry working conditions

- Compressed air is used to keep the water and mud out
- Used to work on river bed
- **Monolithic caisson**
- It is more suitable for off shore construction
- larger than the other types of caisson, but similar to open caissons

Cofferdam

- Temporary enclosure
- Built within or in piers across a body of water
- Allows the enclosed space to be pumped out, creating a dry work environment.
- Cofferdams are usually welded steel structures
- With components consisting of sheet piles, and cross braces
- For dam construction, two cofferdams are usually built, one upstream and one downstream

Coffer dam

Special Form work

Steel Formwork

Special Formwork is a specializing in the design and manufacture of steel formwork for the casting of concrete.

Column Formwork Inc Circular , rectangular , tapered, oval and elliptical

Sea Defence Formwork

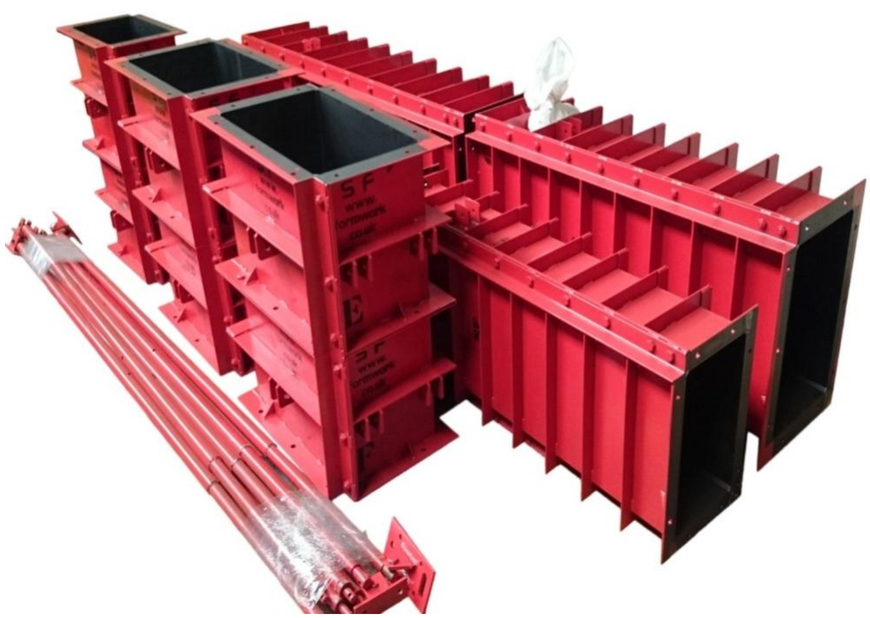
Windfarm Formwork

Tunnel Formwork

Pier & Bridge Formwork

Wall formwork

Formwork for Construction Equipment



Adjustable Column

Adjustable Column

Piers & Bridges

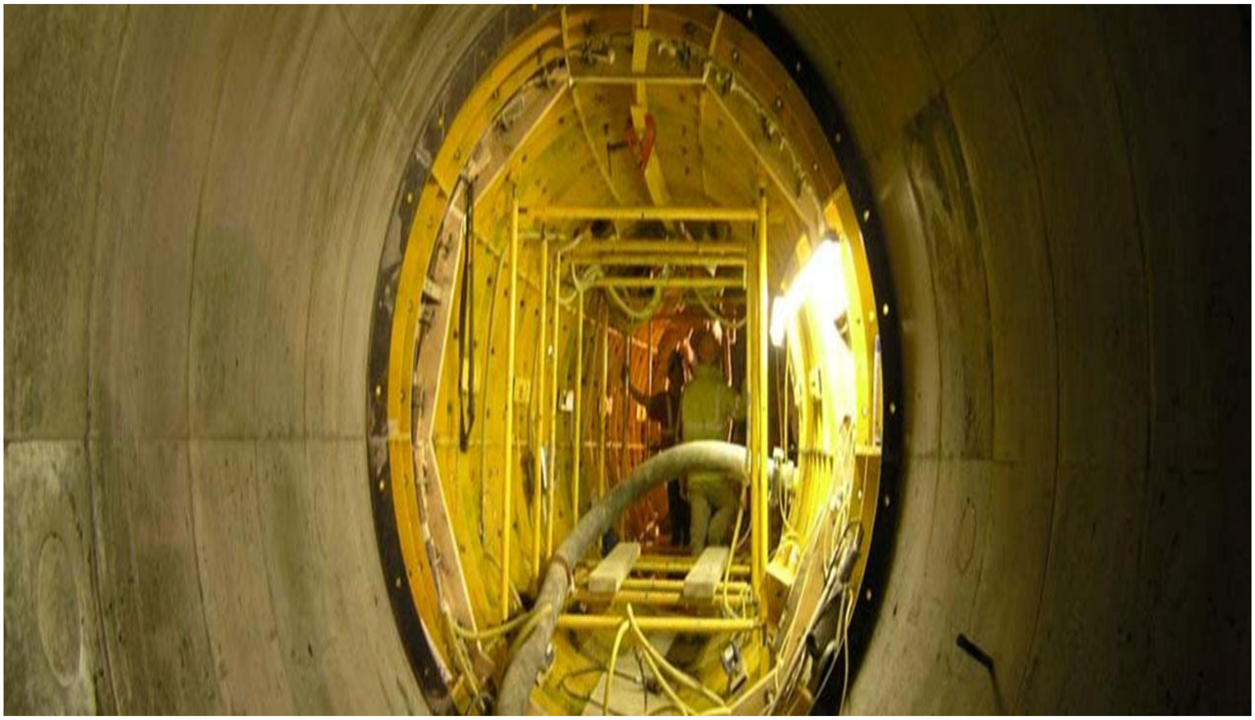
Windfarms

Flexible Windfarm Formwork

Flexible shutters for circular applications can be used to form any diameter upwards of 3 metres. They are ideal for forming circular turbine bases are lightweight and have a high re-use factor. Make-up panels can be supplied to form exactly the diameter required.

Each panel has provision for staking down and attaching purpose made guardrails or standard scaffold can be used.

Column Formwork



Tunnel Formwork

Curved Wall