

DEPARTMENT OF CIVIL ENGINEERING

LECTURE NOTES ON **CONCRETE TECHNOLOGY**



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COURSE CONTENTS:

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GRADES OF CONCRETE

Grades of concrete are defined by the concrete mix proportion and the minimum strength of concrete at end of 28 days curing period. The Concrete Grade is can be known by calculating the compressive strength of concrete in Mpa, where M stands for mix and the MPa denotes the overall strength

There are different types of concrete mix which are based on concrete classification according to its compressive strength.

For making concrete we use cement, sand, aggregate, and water which are mixed with a certain ratio, and concrete is cast and put in a cube of 150 mm size and put in a water bath for 28 days and afterwards, it is tested in a compression testing machine. The compressive stress result is known as the "grade of concrete". It is expressed in N/mm^2

The "M" refers to Mix and Number after M (M10, M20) Indicates the compressive strength of concrete after 28 days of curing and testing.

M indicates the proportion of materials like Cement: Sand: Aggregate (1:2:4) or Cement: Fine Aggregate: Coarse Aggregate.

If we mention M10 concrete, it means that the concrete has 10 N/mm^2 characteristic compressive strength at 28 days.

In the designation of concrete mix M to the mix and the number to the specified compressive strength of 150 mm size cube at 28 days, expressed in N/mm^2 .

Concrete Classification

Following are the **Standard Concrete Grade** with their **Mix Proportions and Strength**

Grades of Concrete	Mix Ratio (Cement : Sand : Aggregates)	Compressive Strength MPa (N/mm^2)	psi
Lower Grade of Concrete			
M5	1 : 5 : 10	5 MPa	725 psi
M7.5	1 : 4 : 8	7.5 MPa	1087 psi
M10	1 : 3 : 6	10 MPa	1450 psi
M15	1 : 2 : 4	15 MPa	2175 psi
M20	1 : 1.5 : 3	20 MPa	2900 psi
Standard Grade of Concrete			
M25	1 : 1 : 2	25 MPa	3625 psi
M30	Design Mix	30 MPa	4350 psi
M35	Design Mix	35 MPa	5075 psi
M40	Design Mix	40 MPa	5800 psi
M45	Design Mix	45 MPa	6525 psi

High Strength Grade of Concrete			
M50	Design Mix	50 MPa	7250 psi
M55	Design Mix	55 MPa	7975 psi
M60	Design Mix	60 MPa	8700 psi
M65	Design Mix	65 MPa	9425 psi
M70	Design Mix	70 MPa	10150 psi

The Selection of the Grade of Concrete Depends on the Situation and Uses:

Concrete Grade (N/mm ²)	Ratio Cement, Sand, and Aggregates	Usage
10	1:3:6	PCC
15	1:2:4	PCC
20	1:1.5:3	Normal Construction Concrete
25	1:1:2	Reinforced concrete/precast
30	Concrete Mix Design	Heavy Reinforced concrete/pre-cast
35	Concrete Mix Design	Pre-stressed/pre-cast concrete
40	Concrete Mix Design	Very heavy reinforced concrete/pre-cast/prestressed
45	Concrete Mix Design	Very heavy reinforced concrete/pre-cast/prestressed

ADVANTAGES AND DISADVANTAGES OF CONCRETE:-

Advantages of Concrete:-

The following are the advantages of concrete :

1. Availability of concrete ingredients easily.
2. Easy handling and moulding of concrete into any shape.
3. Easy transportation from the place of mixing to place of casting before initial set takes place.
4. Ability to pump/spray to fill into cracks and lining of tunnels.
5. When reinforced, all types of the structures are made possible from an ordinary lintel to massive fly overs
6. Monolithic character gives better appearance and much rigidity to the structure.
7. The property of concrete to possess high compressive strength, makes a concrete structure more economical than that of steel structure.

Disadvantages of Concrete:-

The following are the disadvantages of concrete :

1. Due to low tensile strength, concrete is required to be reinforced to avoid cracks.
2. In long structures expansion joints are required to be provided if there is large temperature variance in the area.
3. Construction joints are provided to avoid cracks due to drying shrinkage and moisture-expansion.

4. Soluble salts in concrete cause efflorescence if moisture reacts with them.
5. Concrete made with ordinary Portland cement, gets integrated in the presence of alkalies, sulfates etc.
6. Sustained loads develop creep in structures.

CEMENT:-

cement, in general, adhesive substances of all kinds, but, in a narrower sense, the binding materials used in building and civil engineering construction. Cements of this kind are finely ground powders that, when mixed with water, set to a hard mass. Setting and hardening result from hydration, which is a chemical combination of the cement compounds with water that yields submicroscopic crystals or a gel-like material with a high surface area. Because of their hydrating properties, constructional cements, which will even set and harden under water, are often called hydraulic cements. The most important of these is portland cement.

This article surveys the historical development of cement, its manufacture from raw materials, its composition and properties, and the testing of those properties. The focus is on portland cement, but attention also is given to other types, such as slag-containing cement and high-alumina cement. Construction cements share certain chemical constituents and processing techniques with ceramic products such as brick and tile, abrasives, and refractories. For detailed description of one of the principal applications of cement, see the article building construction.

CEMENT

Cement is a binder, a substance that sets and hardens and can bind other materials together. Cements used in construction can be characterized as being either hydraulic or non-hydraulic, depending upon the ability of the cement to be used in the presence of water. Non-hydraulic cement will not set in wet conditions or underwater, rather it sets as it dries and reacts with carbon dioxide in the air. It can be attacked by some aggressive chemicals after setting. Hydraulic cement is made by replacing some of the cement in a mix with activated aluminum silicates, pozzolana, such as fly ash. The chemical reaction results in hydrates that are not very water-soluble and so are quite durable in water and safe from chemical attack. This allows setting in wet condition or underwater and further protects the hardened material from chemical attack (e.g., Portland cement).

Uses:-

- Cement mortar for Masonry work, plaster and pointing etc.
- Concrete for laying floors, roofs and constructing lintels, beams, weather-shed, stairs, pillars etc.
- Construction of water, wells, tennis courts, septic tanks, lamp posts, telephone cabins etc.
- Making joint for joints, pipes, etc.
- Manufacturing of precast pipes, garden seats, flower posts, etc.
- Preparation of foundation, water tight floors, footpaths, etc.

ORDINARY PORTLAND CEMENT:-

Ordinary Portland cement is the most common type of cement in general use around the world. This cement is made by heating limestone (calcium carbonate) with small quantities of other materials (such as clay) to 1450°C in a kiln, in a process known as calcinations, whereby a molecule of carbon dioxide is liberated from the calcium carbonate to form calcium oxide, or quicklime, which is then blended with the other materials that have been included in the mix. The resulting hard substance, called 'clinker', is then ground with a small amount of gypsum into a powder to make 'Ordinary Portland Cement'(often referred to as OPC). Portland cement is a basic ingredient of concrete, mortar and most non-specialty grout. The most common use for Portland cement is in the production of concrete. Concrete is a composite material consisting of aggregate (gravel and sand), cement, and water. As a construction material, concrete can be cast in almost any shape desired, and once hardened, can become a structural (load bearing) element. Portland cement may be grey or white.

- This type of cement use in construction when there is no exposure to sulphates in the soil or ground water.
- Lime saturation Factor is limited between i.e. 0.66 to 1.02.
- Free lime-cause the Cement to be unsound.
- Percentage of (Al_2O_3/Fe_2O_3) is not less than 0.66.
- Insoluble residue not more than 1.5%.
- Percentage of SO_3 limited by 2.5% when $C_3A < 7\%$ and not more than 3% when $C_3A > 7\%$.
- Loss of ignition -4%(max)
- Percentage of MgO-5% (max.)
- Fineness -not less than $2250 \text{ cm}^2/\text{g}$.

Chemical constituents of cement:-

These are the different constituents which combine to make cement. These are their percentage content in order to give good cement.

Oxide	Per cent content
CaO	60–67
SiO ₂	17–25
Al ₂ O ₃	3.0–8.0
Fe ₂ O ₃	0.5–6.0
MgO	0.1–4.0
0.4–	
Alkalies(K_2O, Na_2O)	1.3
SO ₃	1.3–3.0

Hydration of Cement:-

The chemical reaction between cement and water in a proportioning mix is called as hydration of cement. It may be in concrete mix or in the making of mortar in the field work.

SETTING OF CEMENT:-

The action of changing mixed cement from a fluid state to a solid state is called setting of cement and time required for it to set is called setting time of cement. Setting time of cement is same as setting time of concrete.

SETTING TIME OF CEMENT:-

1. Initial Setting Time

Initial Setting Time is defined as the period elapsing between the time when water is added to the cement and the time at which the needle of 1 mm square section fails to pierce the test block to a depth of about 5 mm from the bottom of the mould. A period of 30 minutes is the minimum initial setting time, specified by ISI for ordinary and rapid hardening Portland cements and 60 minutes for low heat cement.

2. Final Setting Time

Final Setting Time is defined as the period elapsing between the time when water is added to cement and the time at which the needle of 1 mm square section with 5 mm diameter attachment makes an

impression on the test block. 600 minutes is the maximum time specified for the final set for all the above mentioned Portland cement. IS: 269-1976 specifies the strengths in compression on the standard mortar-cube.

STRUCTURE OF HYDRATED CEMENT:-

The desirable engineering characteristics of hardened concrete —strength, dimensional stability, and durability —are influenced not only by the proportion but also by the properties of the hydrated cement paste, which, in turn, depend on the micro-structural features (i.e., the type, amount, and distribution of solids and voids).

Fresh cement paste is a plastic network of particles of cement in water but, once the cement paste has set, its apparent or gross volume remains approximately constant.

At any stage of hydration, the hardened paste consists of hydrates of the various compounds, referred to collectively as gel, crystals of Ca(OH)_2 , some minor components, unhydrated cement and the residue of water-filled spaces in the fresh paste.

VARIOUS TESTS ON CEMENT:

Basically two types of tests are under taken for assessing the quality of cement. These are either field test or lab tests. The current section describes these tests in details.

Field test:

There are four field tests may be carried out to ascertain roughly the quality of cement. There are four types of field tests to access the colour, physical property, and strength of the cement as described below.

Colour:

- The colour of cement should be uniform.
- It should be typical cement colour i.e. grey colour with a light greenish shade.

Physical properties:

- Cement should feel smooth when touched between fingers.
- If hand is inserted in a bag or heap of cement, it should feel cool.

Presence of lumps:

- Cement should be free from lumps.
- For a moisture content of about 5 to 8%, this increase of volume may be much as 20 to 40 %, depending upon the grading of sand.

Strength:

- A thick paste of cement with water is made on a piece of thick glass and it is kept under water for 24 hours. It should set and not crack.

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Laboratory tests:

Six laboratory tests are conducted mainly for assessing the quality of cement. These are: fineness, compressive strength, consistency, setting time, soundness and tensile strength.

Fineness:

- This test is carried out to check proper grinding of cement.
- The fineness of cement particles may be determined either by sieve test or permeability apparatus test.
- In sieve test, the cement weighing 100 gm is taken and it is continuously passed for 15 minutes through standard BIS sieve no. 9. The residue is then weighed and this weight should not be more than 10% of original weight.
- In permeability apparatus test, specific area of cement particles is calculated. This test is better than sieve test. The specific surface acts as a measure of the frequency of particles of average size.

Compressive strength:

- This test is carried out to determine the compressive strength of cement.
- The mortar of cement and sand is prepared in ratio 1:3.
- Water is added to mortar in water cement ratio 0.4.
- The mortar is placed in moulds. The test specimens are in the form of cubes and the moulds are of metals. For 70.6 mm and 76 mm cubes, the cement required is 185 gm and 235 gm respectively.
- Then the mortar is compacted in vibrating machine for 2 minutes and the moulds are placed in a damp cabin for 24 hours.
- The specimens are removed from the moulds and they are submerged in clean water for curing.
- The cubes are then tested in compression testing machine at the end of 3 days and 7 days. Thus compressive strength was found out.

Consistency:

- The purpose of this test is to determine the percentage of water required for preparing cement pastes for other tests.
- Take 300 gm of cement and add 30 percent by weight or 90 gm of water to it.
- Mix water and cement thoroughly.
- Fill the mould of Vicat apparatus and the gauging time should be 3.75 to 4.25 minutes.
- Vicat apparatus consists of a needle attached to a movable rod with an indicator attached to it.
- There are three attachments: square needle, plunger and needle with annular collar.
- The plunger is attached to the movable rod.
- The plunger is gently lowered on the paste in the mould.
- The settlement of plunger is noted. If the penetration is between 5 mm to 7 mm from the bottom of mould, the water added is correct.
- If not process is repeated with different percentages of water till the desired penetration is obtained.
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Setting time:

- This test is used to detect the deterioration of cement due to storage. The test is performed to find out initial setting time and final setting time.
- Cement mixed with water and cement paste is filled in the Vicat mould.
- Square needle is attached to moving rod of Vicat apparatus.
- The needle is quickly released and it is allowed to penetrate the cement paste. In the beginning the needle penetrates completely. The procedure is repeated at regular intervals till the needle does not penetrate completely. (up to 5mm from bottom)
- Initial setting time = <30min for ordinary Portland cement and 60 min for low heat cement.
- The cement paste is prepared as above and it is filled in the Vicat mould.
- The needle with annular collar is attached to the moving rod of the Vicat apparatus.
- The needle is gently released. The time at which the needle makes an impression on test block and the collar fails to do so is noted.
- Final setting time is the difference between the time at which water was added to cement and time as recorded in previous step, and it is <10 hours.

Soundness:

- The purpose of this test is to detect the presence of uncombined lime in the cement.
- The cement paste is prepared.
- The mould is placed and it is filled by cement paste.
- It is covered at top by another glass plate. A small weight is placed at top and the whole assembly is submerged in water for 24 hours.
- The distance between the points of indicator is noted. The mould is again placed in water and heat is applied in such a way that boiling point of water is reached in about 30 minutes. The boiling of water is continued for one hour.
- The mould is removed from water and it is allowed to cool down.

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- The needle is gently released. The time at which the needle makes an impression on test block and the collar fails to do so is noted.
- Final setting time is the difference between the time at which water was added to cement and time as recorded in previous step, and it is ≤ 10 hours.

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- The mould is removed from water and it is allowed to cool down.
- The distance between the points of indicator is again measured. The difference between the two readings indicates the expansion of cement and it should not exceed 10 mm.

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Tensile strength:

- This test was formerly used to have an indirect indication of compressive strength of cement.
- The mortar of sand and cement is prepared.
- The water is added to the mortar.
- The mortar is placed in briquette moulds. The mould is filled with mortar and then a small heap of mortar is formed at its top. It is beaten down by a standard spatula till water appears on the surface. Same procedure is repeated for the other face of briquette.
- The briquettes are kept in a damp for 24 hours and carefully removed from the moulds.
- The briquettes are tested in a testing machine at the end of 3 and 7 days and average is found out.

Compressive strength:

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- The needle is gently released. The time at which the needle makes an impression on test block and the collar fails to do so is noted.
- Final setting time is the difference between the time at which water was added to cement and time as recorded in previous step, and it is <10hours.

Soundness:

- The purpose of this test is to detect the presence of uncombined lime in the cement.
- The cement paste is prepared.
- The mould is placed and it is filled by cement paste.
- It is covered at top by another glass plate. A small weight is placed at top and the whole assembly is submerged in water for 24 hours.
- The distance between the points of indicator is noted. The mould is again placed in water and heat is applied in such a way that boiling point of water is reached in about 30 minutes. The boiling of water is continued for one hour.
- The mould is removed from water and it is allowed to cool down.
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- The briquettes are kept in a damp for 24 hours and carefully removed from the moulds.
- The briquettes are tested in a testing machine at the end of 3 and 7 days and average is found out.

Grade of cement:-

Grade of cement represents the specific 28 days compressive strength. The following three grades are given along with their compressive strengths

- 33 Grade OPC – 33 MPa
- 43 Grade OPC – 43 MPa
- 53 Grade OPC – 53 MPa

ADMIXTURE

Admixture is a compound which is used in order to increase or decrease the initial and final setting time of cement.

Admixture and its types

Chemical admixtures are the ingredients in concrete other than Portland cement, water, and aggregate those are added to the mix immediately before or during mixing. Producers use admixtures primarily to reduce the cost of concrete construction; to modify the properties of hardened concrete; to ensure the quality of concrete during mixing, transporting, placing, and curing; and to overcome certain emergencies during concrete operations.

It is of various types-

Water-reducing admixtures usually reduce the required water content for a concrete mixture by about 5 to 10 percent. Consequently, concrete containing a water-reducing admixture needs less water to reach a required slump than untreated concrete. The treated concrete can have a lower water-cement ratio.

This usually indicates that a higher strength concrete can be produced without increasing the amount of cement. Recent advancements in admixture technology have led to the development of mid-range water reducers. These admixtures reduce water content by at least 8 percent and tend to be more stable over a wider range of temperatures. Mid-range water reducers provide more consistent setting times than standard water reducers.

Retarding admixtures, which slow the setting rate of concrete, are used to counteract the accelerating effect of hot weather on concrete setting. High temperatures often cause an increased rate of hardening which makes placing and finishing difficult. Retarders keep concrete workable during placement and delay the initial set of concrete. Most retarders also function as water reducers and may entrain some air in concrete.

Accelerating admixtures increase the rate of early strength development; reduce the time required for proper curing and protection, and speed up the start of finishing operations. Accelerating admixtures are especially useful for modifying the properties of concrete in cold weather.

Super plasticizers, also known as plasticizers or high-range water reducers (HRWR), reduce water content by 12 to 30 percent and can be added to concrete with a low-to-normal slump and water-

cement ratio to make high-slump flowing concrete. Flowing concrete is a highly fluid but workable concrete that can be placed with little or no vibration or compaction. The effect of super plasticizers lasts only 30 to 60 minutes, depending on the brand and dosage rate, and is followed by a rapid loss in workability. As a result of the slump loss, super plasticizers are usually added to concrete at the jobsite.

Corrosion-inhibiting admixtures fall into the specialty admixture category and are used to slow corrosion of reinforcing steel in concrete. Corrosion inhibitors can be used as a defensive strategy for concrete structures, such as marine facilities, highway bridges, and parking garages, that will be exposed to high concentrations of chloride. Other specialty admixtures include shrinkage-reducing admixtures and alkali-silica reactivity inhibitors. The shrinkage reducers are used to control drying shrinkage and minimize cracking, while ASR inhibitors control durability problems associated with alkali-silica reactivity.

DOSAGES:-

Super plasticizers are commonly known as High Range Water Reducers because it permits low water cement ratio as well as the workability also affected. In very recent decades, super plasticizers creates milestone in the advancement of chemical admixtures for Portland cement concrete. The dramatic effect of super plasticizer (SP) on properties of fresh and hardened concrete has studied and the properties of concrete inspected are compressive strength and slump test. To determine the optimum dosage for the admixture, an experimental investigation conducted and the effect of over dosage of the SP admixture experimented, together with one control mixed. The viscosity of grout and hence the workability of concrete influenced by the dosage of super plasticizer. From dosages of admixture, the difference between concrete mixes comes, which used at amounts 400 ml/100 kg, 600 ml/100 kg, 800 ml/100 kg, 1000 ml/100 kg and 1200 ml/100 kg of cement were prepared. By dosage 1.0% of SP, compressive strength is improved and after 28 days curing it is 57 N/mm^2 , which is higher than that of control specimen.

AGGREGATE

Aggregates are defined as inert, granular, and inorganic materials that normally consist of stone or stone-like solids. Aggregates can be used alone (in road bases and various types of fill) or can be used with cementing materials (such as Portland cement or asphalt cement) to form composite materials or concrete.

Classification of aggregates based on: Grain Size

If you separate aggregates by size, there are two overriding categories:

- Fine aggregates
- Coarse aggregates

The size of fine aggregates is defined as 4.75mm or smaller. That is, aggregates which can be passed through a number 4 sieve, with a mesh size of 4.75mm. Fine aggregates include things such as sand, silt and clay. Crushed stone and crushed gravel might also fall under this category.

Typically, fine aggregates are used to improve workability of a concrete mix.

Coarse aggregates measure above the 4.75mm limit. These are more likely to be natural stone or gravel that has not been crushed or processed. These aggregates will reduce the amount of water needed for a concrete mix, which may also reduce workability but improve its innate strength.

Classification of aggregates based on: Density

There are three weight-based variations of aggregates:

- Lightweight
- Standard
- High density

Different density aggregates will have much different applications. Lightweight and ultra lightweight aggregates are more porous than their heavier counterparts, so they can be put to great use in green roof

construction, for example. They are also used in mixes for concrete blocks and pavements, as well as insulation and fireproofing.

High density aggregates are used to form heavyweight concrete. They are used for when high strength, durable concrete structures are required – building foundations or pipe work ballasting, for example.

Classification of aggregates based on: Geographical Origin

Another way to classify aggregates is by their origin. You can do this with two groups:

- Natural – Aggregates taken from natural sources, such as riverbeds, quarries and mines. Sand, gravel, stone and rock are the most common, and these can be fine or coarse.
- Processed – Also called ‘artificial aggregates’, or ‘by-product’ aggregates, they are commonly taken from industrial or engineering waste, then treated to form construction aggregates for high quality concrete. Common processed aggregates include industrial slag, as well as burnt clay. Processed aggregates are used for both lightweight and high-density concrete mixes.

Classification of aggregates based on: Shape

Shape is one of the most effective ways of differentiating aggregates. The shape of your chosen aggregates will have a significant effect on the workability of your concrete. Aggregates purchased in batches from a reputable supplier can be consistent in shape, if required, but you can also mix aggregate shapes if you need to.

The different shapes of aggregates are:

- Rounded – Natural aggregates smoothed by weathering, erosion and attrition. Rocks, stone, sand and gravel found in riverbeds are your most common rounded aggregates. Rounded aggregates are the main factor behind workability.
- Irregular – These are also shaped by attrition, but are not fully rounded. These consist of small stones and gravel, and offer reduced workability to rounded aggregates.
- Angular – Used for higher strength concrete, angular aggregates come in the form of crushed rock and stone. Workability is low, but this can be offset by filling voids with rounded or smaller aggregates.
- Flaky – Defined as aggregates that are thin in comparison to length and width. Increases surface area in a concrete mix.
- Elongated – Also adds more surface area to a mix – meaning more cement paste is needed. Elongated aggregates are longer than they are thick or wide.
- Flaky and elongated – A mix of the previous two – and the least efficient form of aggregate with regards to workability.

Particle shape and Texture:-

Aggregate particle shape and surface texture are important for proper compaction, deformation resistance, and workability. However, the ideal shape for HMA and PCC is different because aggregates serve different purposes in each material. In HMA, since aggregates are relied upon to provide stiffness and strength by interlocking with one another, cubic angular-shaped particles with a rough surface texture are best. However, in PCC, where aggregates are used as an inexpensive high-strength material to occupy volume, workability is the major issue regarding particle shape. Therefore, in PCC rounded particles are better. Relevant particle shape/texture characteristics are discussed below.

Rounded particles create less particle-to-particle interlock than angular particles and thus provide better workability and easier compaction. However, in HMA less interlock is generally a disadvantage as rounded aggregate will continue to compact, shove and rut after construction. Thus angular particles are desirable for HMA (despite their poorer workability), while rounded particles are desirable for PCC because of their better workability.

Flat or Elongated Particles

These particles tend to impede compaction or break during compaction and thus, may decrease strength.

Smooth-Surfaced Particles

These particles have a lower surface-to-volume ratio than rough-surfaced particles and thus may be easier to coat with binder. However, in HMA asphalt tends to bond more effectively with rough-surfaced particles, and in PCC rough-surfaced particles provide more area to which the cement paste can bond. Thus, rough-surface particles are desirable for both HMA and PCC.

ENGINEERING PROPERTIES OF AGGREGATES:-

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

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

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

1. COMPOSITION

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

2. SIZE & SHAPE

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

Maximum size of aggregate should be less than

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

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

3. SURFACE TEXTURE

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

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

4. SPECIFIC GRAVITY

The ratio of weight of oven dried aggregates maintained for 24 hours at a temperature of 100 to 110⁰C, to the weight of equal volume of water displaced by saturated dry surface aggregate is known as specific gravity of aggregates.

Specific gravities are primarily of two types.

- Apparent specific gravity
- Bulk specific gravity

Specific gravity is a mean to decide the suitability of the aggregate. Low specific gravity generally indicates porous, weak and absorptive materials, whereas high specific gravity indicates materials of good quality. Specific gravity of major aggregates falls within the range of 2.6 to 2.9.

Specific gravity values are also used while designing concrete mix.

5. BULK DENSITY

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

Bulk density of aggregates depends upon the following 3 factors.

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

6. VOIDS

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

7. POROSITY & ABSORPTION

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

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

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

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

8. BULKING OF SAND

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

Fine sands bulk more than coarse sand

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

9. FINENESS MODULUS

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

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

10. SPECIFIC SURFACE OF AGGREGATE

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

11. DELETERIOUS MATERIALS

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

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

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

- Organic impurities
- Clay, silt & dust
- Salt contamination

12. CRUSHING VALUE

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

13. IMPACT VALUE

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

14. ABRASION VALUE OF AGGREGATES

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

SIEVE ANALYSIS:-

Sieve analysis is a technique used to determine the particle size distribution of a powder. This method is performed by sifting a powder sample through a stack of wire mesh sieves, separating it into discrete size ranges. A sieve shaker is used to vibrate the sieve stack for a specific period of time.

Sieve analysis is important for analyzing materials because particle size distribution can affect a wide range of properties, such as the strength of concrete, the solubility of a mixture, surface area properties and even their taste.

FINENESS MODULUS:-

The *Fineness Modulus* (FM) is an empirical figure obtained by adding the total percentage of the sample of an aggregate retained on each of a specified series of sieves, and dividing the sum by 100.

Fineness modulus of sand (fine aggregate) is an index number which represents the mean size of the particles in sand. It is calculated by performing sieve analysis with standard sieves. The cumulative percentage retained on each sieve is added and subtracted by 100 gives the value of fineness modulus.

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

THE GRADING CURVE:-

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

GRADING OF AGGREGATES:-

Grading of aggregates is determining the average grain size of the aggregates before they are used in construction. This is applied to both coarse and fine aggregates. The aggregate sample is sieved through a set of sieves and weights retained on each sieve in percentage terms are summed up.

GAP GRADING AGGREGATE:-

Gap grading is defined as a grading in which one or more intermediate size fractions are absent. On a grading curve, it represents a horizontal line over the range of sizes that are absent.

MAXIMUM AGGREGATE SIZE:-

Typically, coarse aggregate sizes are larger than 4.75 mm (5 mm in British code), while fine aggregates form the portion below 4.75 mm. A maximum size up to 40 mm is used for coarse aggregate in most structural applications, while for mass concreting purposes such as dams, sizes up to 150 mm may be used.

FRESH CONCRETE

Workability is the property of concrete which determines the amount of internal work necessary to produce full compaction. It is a measure with which concrete can be handled from the mixer stage to its final fully compacted stage.

FACTORS AFFECTING WORKABILITY OF CONCRETE:-

01. Water Content of the Concrete Mix:

Water content will have important influences on the workability in given volume of concrete. The higher the water content per cubic meter of concrete, the higher will be the fluidity of concrete, which affect the workability.

Water requirement is mainly associated with absorption by aggregates surface & filling up the voids between aggregates.

- The strength of the concrete may get reduced.
- More quantity of water comes out from the surface of concrete resulting into bleeding.
- Cement slurry also escapes through the joints of formwork resulting into the loss of cement from concrete.

02. The Size of Aggregates:

Workability is mainly governed by the maximum size of aggregates. Water and paste require, will be not less if a chosen size of aggregates for concrete is bigger. Consequently, for a given quantity of water content & paste, bigger size aggregate will give higher workability.

Note: On the site, the maximum size of aggregate to be used will depend upon the many factors such as the handling, mixing and placing equipment, the thickness of section and quantity of reinforcement. Later two are very important.

03. The shape of Aggregates:

Angular, flaky & elongated aggregate reduces the workability of concrete.

Rounded or sub-rounded aggregates increase the workability due to the reduction of surface area for a given volume or weight. Therefore, an excess paste is available to give better lubricating effect.

Rounded shape aggregate has less frictional resistance and gives a high workability as compared to angular, flaky or elongated aggregates.

Note: River sand & gravel provide greater workability to concrete than crushed sand.

04. Surface Texture of Aggregates:

The roughly textured aggregates have more surface area than smoothly rounded aggregates of the same volume. Smooth rounded or glassy aggregates will give better workability than roughly textured aggregates. A reduction of inter particle frictional resistance offered by smooth aggregates also contributes to higher workability.

05. The Porosity of Aggregates:

Porous and non-saturated aggregate will require more water than non-absorbent aggregates. For the same degree of workability, latter will require less water. Overall, this factor is only of secondary importance.

06. Grading of Aggregates:

Grading of aggregates has the greatest influence on workability. The better the grading of aggregates, the less is the amount of void in concrete so well-graded aggregates should be used. When total voids are less in concrete, the excess paste is available to give better lubricating effect.

With excess amount of concrete paste present in the mixture, it becomes cohesive and fatty that prevents segregation of particles & least amount of compacting efforts is required to compact the concrete.

For a given workability, there is one value of coarse aggregate / Fine aggregate ratio, which needs the lower water content.

07. Uses of Concrete Admixtures:

This is one of the commonly used methods to enhance the workability of concrete. Concrete admixtures such as plasticizer and super plasticizers greatly improve the workability.

Air entraining agents are also used to increase the workability. Air entraining agents create a large number of very tiny air bubbles. These bubbles get distributed throughout the mass of concrete and act as rollers and increase the workability.

Mineral admixtures like Pozzolanic materials are also used to improve the workability of concrete.

08. Ambient Temperature:

In hot weather, if temperature increases, the evaporation rate of mixing water also increases and hence fluid viscosity increases, too. This phenomenon affects the flowability of concrete and due to fast hydration of concrete; it will gain strength earlier which decreases the workability of fresh concrete.

Measurement of Workability:-

The following tests for workability of concrete give a measure of workability, which is applicable specifically concerning some particular methods. They bear no relationship to any of the common methods of placing and compacting concrete. So, the test results are only relative and should not be given any absolute measurement. We need to understand that each test has its importance, and as such there is no unique test to measure the workability of concrete in total. The significant advantage is the simplicity of the procedure with an ability to detect variation in the uniformity of a mix of given nominal proportion.

Types of tests for workability:-

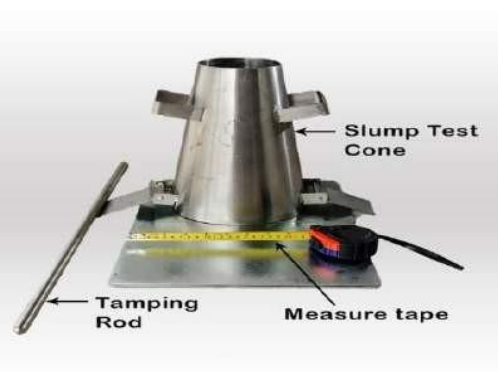
- Slump Test
- Compacting Factor Test
- Flow Test
- Vee-Bee Consistometer Test

SLUMP TEST:-

The slump test is a means of assessing the consistency of fresh concrete. It is used, indirectly, as a means of checking that the correct amount of water has been added to the mix.

The steel slump cone is placed on a solid, impermeable, level base and filled with the fresh concrete in three equal layers. Each layer is rodded 25 times to ensure compaction. The third layer is finished off level with the top of the cone. The cone is carefully lifted up, leaving a heap of concrete that settles or 'slumps' slightly. The upturned slump cone is placed on the base to act as a reference, and the difference in level between its top and the top of the concrete is measured and recorded to the nearest 10mm to give the slump of the concrete.

When the cone is removed, the slump may take one of three forms. In a true slump the concrete simply subsides, keeping more or less to shape. In a shear slump the top portion of the concrete shears off and slips sideways. In a collapse slump the concrete collapses completely. Only a true slump is of any use in the test. If a shear or collapse slump is achieved, a fresh sample should be taken and the test repeated. A collapse slump will generally mean that the mix is too wet or that it is a high workability mix, for which the flow test (see separate entry) is more appropriate.



- **Compacting Factor Test:-**

The compacting factor test is designed primarily for use in the laboratory but it can also be used in the field. It is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability as are normally used when concrete is to be compacted by vibration. Such dry concrete are insensitive to slump test.

The degree of compaction, called the compacting factor is measured by the density ratio i.e., the ratio of the density actually achieved in the test to density of same concrete fully compacted. The sample of concrete to be tested is placed in the upper hopper up to the brim. The trap-door is opened so that the concrete falls into the lower hopper. Then the trap-door of the lower hopper is opened and the concrete is allowed to fall into the cylinder. In the case of a dry-mix, it is likely that the concrete may not fall on opening the trap-door. In such a case, a slight poking by a rod may be required to set the concrete in motion. The excess concrete remaining above the top level of the cylinder is then cut off with the help of plane blades supplied with the apparatus. The outside of the cylinder is wiped clean. The concrete is filled up exactly up to the top level of the cylinder. It is weighed to the nearest 10 grams. This weight is known as —Weight of partially compacted concrete.

The cylinder is emptied and then refilled with the concrete from the same sample in layers approximately 5 cm deep. The layers are heavily rammed or preferably vibrated so as to obtain full compaction. The top surface of the fully compacted concrete is then carefully struck off level with the top of the cylinder and weighed to the nearest 10 gm. This weight is known as Weight of fully compacted concrete.

The compaction factor = $\frac{\text{Weight of partially compacted concrete}}{\text{Weight of fully compacted concrete}}$

FLOW TEST

This is a laboratory test, which gives an indication of the quality of concrete with respect to consistency, cohesiveness and the proneness to segregation. In this test, a standard mass of concrete is subjected to joint. The spread or the flow of the concrete is measured and this flow is related to workability.

It can be seen that the apparatus consists of flow table, about 76 cm. in diameter over which concentric circles are marked. A mould made from smooth metal casting in the form of a frustum of a cone is used with the following internal dimensions. The base is 25 cm. in diameter, upper surface 17 cm. in diameter, and height of the cone is 12 cm. The table top is cleaned of all gritty material and is wetted. The mould is kept on the centre of the table, firmly held and is filled in two layers. Each layer is rodded 25 times with a tamping rod 1.6 cm in diameter and 61 cm long rounded at the lower tamping end. After the top layer is rodded evenly, the excess of concrete which has overflowed the mould is removed. The mould is lifted vertically upward and the concrete stands on its own without support. The table is then raised and dropped 12.5 mm 15 times in about 15 seconds. The diameter of the spread concrete is measured in about 6 directions to the nearest 5 mm and the average spread is noted. The flow of concrete is the percentage increase in the average diameter of the spread concrete over the base diameter of the mould.

$$\text{Flow per cent} = \frac{\text{Spread diameter in cm} - 25}{25} \times 100$$

The value could range anything from 0 to 150 per cent. A close look at the pattern of spread of concrete can also give a good indication of the characteristics of concrete such as tendency for segregation.

- **VEE-BEE CONSISTOMETER TEST**

This is a good laboratory test to measure indirectly the workability of concrete. This test metal cylindrical pot of the consistometer consists of a vibrating table, a metal pot, a sheet metal cone, a standard iron rod. Slump test as described earlier is performed, placing the slump cone inside the sheet. The glass disc attached to the swivel arm is turned and placed on the top of the concrete in the pot. The electrical vibrator is then switched on and simultaneously a stop watch started.

The vibration is continued till such a time as the conical shape of the concrete disappears and the concrete assumes a cylindrical shape. This can be judged by observing the glass disc from the top for disappearance of transparency. Immediately when the concrete fully assumes a cylindrical shape, the stop watch is switched off. The time required for the shape of concrete to change from slump cone shape to cylindrical shape in seconds is known as Vee Bee Degree. This method is very suitable for very dry concrete whose slump value cannot be measured by Slump Test but the vibration is too vigorous for concrete with a slump greater than about 50 mm.

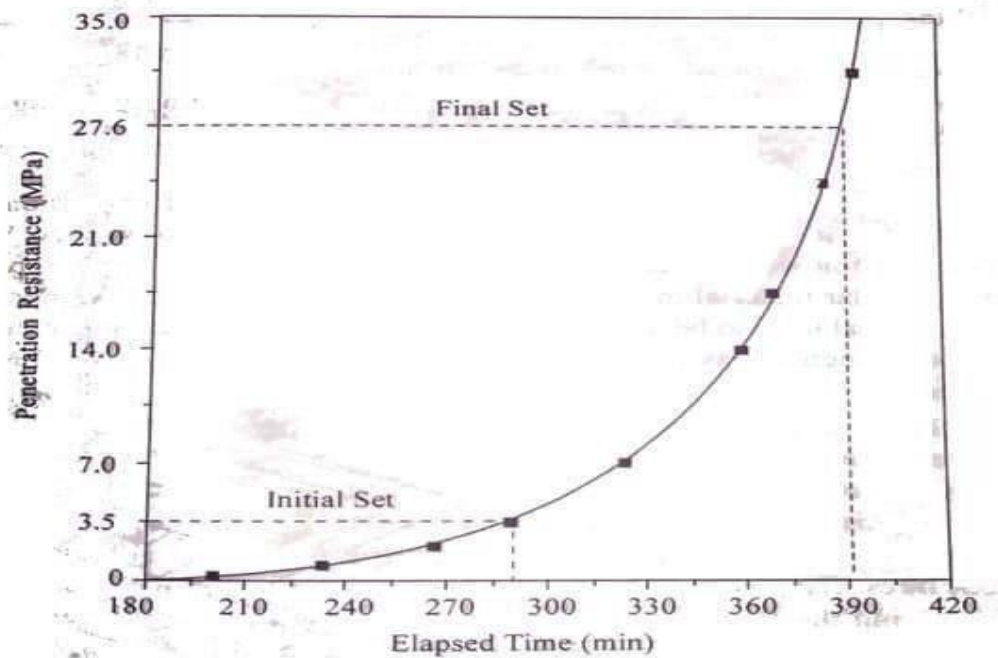
SETTING TIME OF CEMENT:-

The concrete setting time mostly depends upon the w/c ratio, temperature conditions, type of cement, use of mineral admixture, use of plasticizer, in particular, retarding plasticizer. The significance of setting parameter of concrete is more important for site engineers than setting time of cement. For keeping the concrete we use retarding plasticizers, which increases setting time and the duration up to which concrete remains in the plastic condition is of special interest.

The concrete setting time is determined by using a penetrometer test. The test procedure involves,

1. Taking a sufficient quantity of fresh concrete mix sample and sieves it through 4.75 mm sieve.
2. The mortar sample passed through the sieve is collected.
3. This mortar is then compacted by rodding, tapping, rocking or by vibrating.

4. Level the surface and keep it covered to prevent the loss of moisture.
5. Remove bleeding water, if any, using a pipette. Insert a needle of appropriate size, depending upon the degree of the setting of the mortar, in the following manner.
6. Bring the bearing surface of the needle in contact with the mortar surface.
7. Gradually and uniformly apply a vertical force downwards on the apparatus until the needle penetrates to a depth of 25 ± 1.5 mm, as indicated by the scribe mark.
8. The time taken to penetrate 25 mm depth could be about 10 seconds.
9. Record the force required to produce 25 mm penetration and the time of inserting from the time water is added to the cement.
10. Calculate the penetration resistance by dividing the recorded force by the bearing area of the needle. This is the penetration resistance.



- Plot a graph of penetration resistance as ordinate and elapsed time as abscissa.
- Test conducted must determine 6 penetration resistances.
- Continue the tests until one penetration resistance of at least 27.6 MPa is reached.
- Plot these penetration resistance values on the graph and connect each point.
- Now draw a horizontal line from penetration resistance equal to 3.5 MPa.
- The point of intersection of this with the smooth curve is read on the x-axis which gives the initial setting time.
- Similarly, a horizontal line is drawn from the penetration resistance of 27.6 MPa and point it cuts the smooth curve is read on the x-axis which gives the final set.

Effect of time and temp in workability:-

Temperature decreases the setting time by increasing hydration rate and that increase the early age strength of the concrete. This is an advantage that less time will be required before removing of formworks on site, but this decrease the use of proper placement of concrete in the initial stages.

It indicates that the temperature has a negative effect on the workability of concrete as well as strength up to some extent. Temperature decreases the setting time by increasing hydration rate and that increase the early age strength of the concrete.

This is an advantage that less time will be required before removing of form works on site, but this decrease the use of proper placement of concrete in the initial stages. And if concrete is not properly laid, then strength distribution will not remain the same throughout the cross-section.

SEGREGATION:-

The tendency of separation of coarse aggregates grains from the concrete mass is called segregation.

The tendency of water to rise to the surface of freshly laid concrete is known as bleeding.

MIXING AND VIBRATION OF CONCRETE:

Mixing is the uniform incorporation of the ingredients within the concrete mix and vibration usually means the mechanical process to assist in the removal of any entrapped air. The air entrapment causes a honeycomb effect which weakens the concrete,

There are calculations and processes for concrete to allow for movement, which often translates to vibration due to friction or the dissimilarity of materials, a serious concern as it would be the cause for structural fatigue and failure.

The stages of concrete production are:

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

For good quality concrete a proper and accurate quantity of all the ingredients should be used. The aggregates, cement and water should be measured with an accuracy of 3 per cent of batch quantity and the admixtures by 5 per cent of the batch quantity. There are two prevalent methods of batching materials, the volume batching and the weigh batching. The factors affecting the choice of batching method are the size of job, required production rate, and required standards of batching performance. For most important works weigh batching is recommended.

- a) Volume Batching
- b) Weigh Batching

1. Hand Mixing
2. Machine Mixing

- a) Tilting Mixers
- b) Non-tilting Mixer
- c) Reversing Drum Mixer
- d) Pan-type or Stirring Mixer
- e) Transit Mixer

Charging the Mixer and Mixing Time

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

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

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

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

Transporting

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

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

h. Pumping

Placing:

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

Compaction

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

durability of concrete largely depend upon the degree of compaction. For maximum strength driest possible concrete should be compacted 100 per cent.

The compaction of concrete can be achieved by the following methods.

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

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

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

Methods of Curing:

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

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

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

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

QUALITY OF MIXING WATER:-

The common specifications regarding quality of mixing water is water should be fit for drinking. Such water should have inorganic solid less than 1000 ppm. This content lead to a solid quantity 0.05% of mass of cement when w/c ratio is provided 0.5 resulting small effect on strength.

HARDENED CONCRETE

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

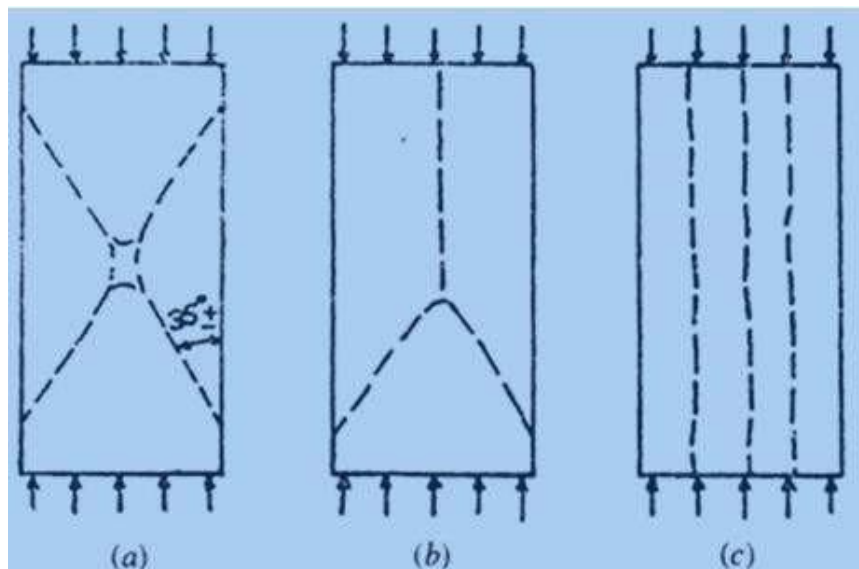
A maximum of 0.5 ratio when concrete is exposed to freezing and thawing in a moist condition or to de-icing chemicals, and a maximum of 0.45 ratio for concrete in a severe or very severe sulphate condition.

However, a mix with a ratio of 0.35 may not mix thoroughly, and may not flow well enough to be placed. More water is therefore used than is technically necessary to react with cement. Water–cement ratios of 0.45 to 0.60 are more typically used. For higher-strength concrete, lower ratios are used, along with a plasticizer to increase flow ability.

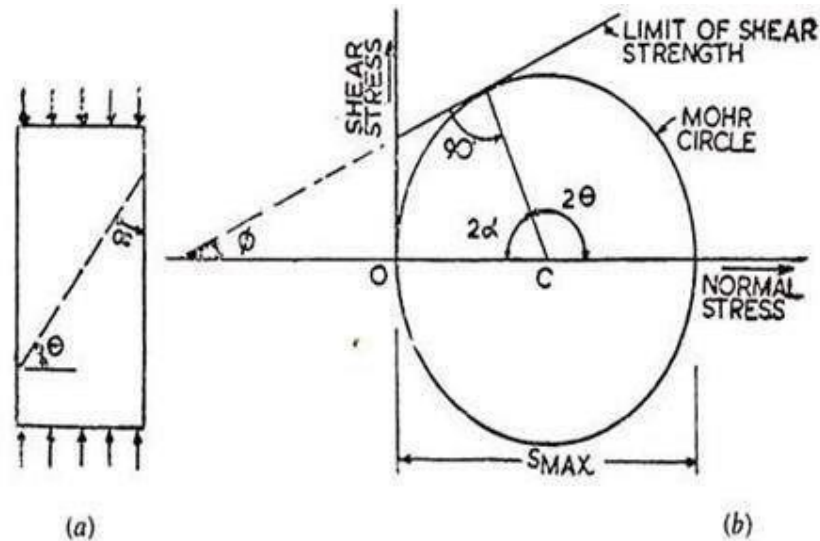
Nature of strength of concrete:-

The strength can be defined as the ability to resist force. With-regard to concrete for structural purposes it can be defined as the unit force required to cause rupture. Strength is a good index of most of the other properties of practical importance. In general stronger concretes are stiffer, more water tight and more resistant to weathering etc.

Rupture of concrete may be caused by applied tensile stress, shearing stress or by compressive stress or a combination of two of the above stresses. Concrete being a brittle material is much weaker in tension and shear than compression and failures of concrete specimens under compressive load are essentially shear failures on oblique planes as shown in fig.



It is called as shear or cone failure. As the resistance to failure is due to both cohesion and internal friction, the angle of rupture is not 45° (plane of maximum shear stress), but is a function of the angle of internal friction. It can be shown mathematically that the angle ϕ which the plane of failure makes with the axis of loading is equal to $(45^\circ - \phi/2)$ as shown in fig.



The angle of internal friction ϕ of concrete being of the order of 20° , the angle of inclination of the cone of failure in the conventional test specimen is approximately 35° as shown in fig.

Maturity of concrete:-

Concrete maturity is an index value that represents the progression of concrete curing. It is based on an equation that takes into account concrete temperature, time, and strength gain. Concrete maturity is an accurate way to determine real-time strength values of curing concrete.

Tension Vs. Compression of Concrete:-

Concrete has enormous compressive strength, the ability to withstand heavy weights or forces on it. It also gains strength as it ages. Concrete will solidify in a few hours and harden or set in a few days, but continues to gain strength for at least 28 days. Some very thick concrete structures, like dams, will continue to gain strength for months or years.

Concrete has almost no tensile strength, the ability to withstand pressing or stretching. Put a board between two supports and press down on the centre. It will bend. The top of the board is under compression, the bottom which bends is under tension. Concrete can resist the compression, but will break under the tension. Concrete cracks in roads and slabs are largely due to tension; different weights in different areas produce tensile forces.

The tension to compression ratio for concrete is about 10 to 15 percent. That is, it can withstand about 10 times the pushing force or compression of the pulling force or tension. Both strengths increase with age, but the ratio is steady. Portland cement concrete less than a year old has compression strength of 1,000 pounds per square inch (psi) and tension strength of 200 psi. Concrete more than a year old has compression psi of 2,000 pounds and tension psi of 400.

Factors affecting strength of concrete:

Concrete strength is affected 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.

Relation between tensile and compressive strength of concrete:-

The theoretical compressive strength of concrete is eight times larger than its tensile strength. This implies a fixed relation between the compressive and tensile strength of concrete. In fact there is a closer relation but not a direct proportionality. The ratio of tensile to compressive strength is lower for higher compressive strengths.

This may be due to the following two reasons:

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

Curing of Concrete:-

Curing of Concrete is a method by which the concrete is protected against loss of moisture required for hydration and kept within the recommended temperature range. Curing will increase the strength and decrease the permeability of hardened concrete.

MOD III TESTING OF HARDENED CONCRETE

The compressive strength of concrete is considered the basic character of the concrete. Consequently, it is known as the characteristic compressive strength of concrete (f_{ck}) which is defined as that value below which not more than five percent of test results are expected to fall based on IS: 456-2000. In this definition the test results are based on 150 mm cube cured in water under temp. of $27 \pm 2^\circ\text{C}$ for 28 days and tested in the most saturated condition under direct compression.

Other strength like, direct tensile stress, flexural stress, shear stress and bond stress also are directly proportional to the compressive stress. Higher is the compressive stress, higher is other stresses also. Not only stresses, other properties for example modulus of elasticity, abrasion and impact resistances, durability are also taken to be related to the compressive strength, hence, the compressive strength is an index of overall quality of concrete.

Factors Affecting Compressive Strength:-

Among the materials and mix variables, water -cement ratio is the most important parameter governing the compressive strength. Besides W/C ratio, following factors also affect the compressive strength.

- I. The characteristics of cement.
- II. The characteristics and properties of aggregates.
- III. The degree of compaction
- IV. The efficiency of curing
- V. Age at the time of testing.
- VI. Conditions of testing.

TENSILE STRENGTH:

- Tensile strength of concrete under direct tension is very small and generally neglected in normal design practice. Although the value ranges from 8 to 12% of its compressive strength. An average value 10% is the proper choice. The direct tension method suffers the problem like holding the specimen properly in the testing machine and the application of uniaxial tensile load not being free of eccentricity.
- The tensile strength can be calculated indirectly by loading a concrete cylinder to the compressive force along the two opposite ends (with its axis horizontal)
- Due to uniform tensile stress acting horizontally along the length of cylinder, the cylinder splits into two halves. The magnitude of this tensile stress (acting in a direction perpendicular to the line of action of applied compression) is given by

The indirect tensile stress is known as splitting tensile strength. FLEXURAL STRENGTH

- The maximum tensile stress resisted by the plain concrete in flexure (bending) is called flexural strength (or modulus of rupture) expressed in N/mm^2 or kg/m^2 .
- The most common plain concrete subjected to flexure is a highway/runway pavement. The strength of pavement concrete is evaluated by means of bending on beam specimen.
- The flexural strength (modulus of rupture) is determined by testing standard test specimens of 150 mm x 150 mm x 700 mm over a span of 600 mm or 100 mm x 100 mm x 500 mm over a span of 400 mm. under symmetrical two point loading.

SHEAR STRENGTH:

- Shear strength is the capacity of concrete to resist the sliding of the section over the adjacent section. A good amount of shear strength capacity is possessed by concrete depending upon the grade of concrete and percentage of tensile reinforcement in the section.
- It is difficult to obtain shear strength of concrete but I.S. code suggests the value for different grade of concrete.

PULL OUT TEST OF CONCRETE:

The pullout test produces a well defined cone in the concrete and measure a static strength property of concrete. The equipment is simple to assemble and operate. The compressive strength can be considered as proportional to the ultimate pullout force. The reliability of the test is reported as good.

NON-DESTRUCTIVE TESTING OF CONCRETE (NDT ON CONCRETE):-

Non destructive test is a method of testing existing concrete structures to assess the strength and durability of concrete structure. In the non destructive method of testing, without loading the specimen to failure (i.e. without destructing the concrete) we can measure strength of concrete. Now days this method has become a part of quality control process. This method of testing also helps us to investigate crack depth, micro cracks and deterioration of concrete.

Non destructive testing of concrete is a very simple method of testing but it requires skilled and experienced persons having some special knowledge to interpret and analyze test results. DIFFERENT METHODS OF NON-DESTRUCTIVE TESTING OF CONCRETE:-

Various non-destructive methods of testing concrete have been developed to analyze properties of hardened concrete, which are given below.

1. SURFACE HARDNESS TEST

These are of indentation type, include the Williams testing pistol and impact hammers, and are used only for estimation of concrete strength.

2. REBOUND HAMMER TEST

The rebound hammer test measures the elastic rebound of concrete and is primarily used for estimation of concrete strength and for comparative investigation.

3. PENETRATION AND PULLOUT TECHNIQUES

These include the use of the simbi hammer, spit pins, the Windsor probe, and the pullout test. These measure the penetration and pullout resistance of concrete and are used for strength estimation, but they can also be used for comparative studies.



NDT test on concrete

4. DYNAMIC OR VIBRATION TESTS

These include resonant frequency and mechanical sonic and ultrasonic pulse velocity methods. These are used to evaluate durability and uniformity of concrete and to estimate its strength and elastic properties.

5. COMBINED METHODS

The combined methods involving ultrasonic pulse velocity and rebound hammer have been used to estimate strength of concrete.

6. RADIOACTIVE AND NUCLEAR METHODS

These include the X-ray and Gamma ray penetration tests for measurement of density and thickness of concrete. Also, the neutron scattering and neutron activation methods are used for moisture and cement content determination.

7. MAGNETIC AND ELECTRICAL METHODS

The magnetic methods are primarily concerned with determining cover of reinforcement in concrete, whereas the electrical methods, including microwave absorption techniques, have been used to measure moisture content and thickness of concrete.

8. ACOUSTIC EMISSION TECHNIQUES

These have been used to study the initiation and growth of cracks in concrete.

ELASTICITY, CREEP, SHRINKAGE

Modulus of Elasticity of Concrete can be defined as the slope of the line drawn from stress of zero to a compressive stress of $0.45f'_c$. As concrete is a heterogeneous material. The strength of concrete is dependent on the relative proportion and modulus of elasticity of the aggregate.

Dynamic modulus is the ratio of stress to strain under vibratory conditions (calculated from data obtained from either free or forced vibration tests, in shear, compression, or elongation). It is a property of visco elastic materials.

Dynamic Modulus:-

The value of modulus of elasticity E_c determined by actual loading of concrete is known as static modulus of elasticity. This method of testing is known as destructive method as the specimen is stressed or loaded till its failure. The static modulus of elasticity does not represent the true elastic behaviour of concrete due to the phenomenon of creep. At higher stresses the modulus of elasticity is affected more seriously.

Thus a non-destructive method of testing known as dynamic method is adopted for determining the modulus of elasticity. In this case no stress is applied on the specimen. The modulus of elasticity is determined by subjecting the specimen to longitudinal vibration at their natural frequency that is why this is known as dynamic modulus.

Poisson's ratio:-

Poisson's ratio is the ratio of lateral strain to longitudinal strain in a material subjected to loading. Poisson's ratio varies between 0.1 for high strength concrete and 0.2 for weak mixes. It is normally taken as 0.15 for strength design and 0.2 for serviceability criteria.

Creep:-

Creep in concrete is defined as the deformation of structure under sustained load. Basically, long term pressure or stress on concrete can make it change shape. This deformation usually occurs in the direction the force is being applied. Like a concrete column getting more compressed, or a beam bending. Creep does not necessarily cause concrete to fail or break apart. When a load is applied to concrete, it experiences an instantaneous elastic strain which develops into creep strain if the load is sustained.

Creep is factored in when concrete structures are designed. Factors Affecting Creep:-

These are the factors which affect creep of concrete.

1. Aggregate
2. Mix Proportions

3. Age of concrete

The magnitude of creep strain is one to three times the value of the instantaneous elastic strain, it is proportional to cement-paste content and, thus, inversely proportional to aggregate volumetric content. The magnitude of creep is dependent upon the magnitude of the applied stress, the age and strength of the concrete, properties of aggregates and cementitious materials, amount of cement paste, size and shape of concrete specimen, volume to surface ratio, amount of steel reinforcement, curing conditions, and environmental conditions.

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. An increase from 65 to 75 % of volumetric content of the aggregate will decrease the creep by 10 %.

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.

Unlike brittle fracture, creep deformation does not occur suddenly upon the application of stress. Instead, strain accumulates as a result of long-term stress. Therefore, creep is a "time-dependent" deformation. It works on the principle of Hooke's law (stress is directly proportional to strain).

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 lead 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.
- Because of rapid construction techniques, concrete members will experience loads that can be as large as the design loads at very early age; these can cause deflections due to cracking and early age low elastic modulus. So, creep has a significant effect on both the structural integrity and the economic impact that it will produce if predicted wrong.

Shrinkage:-

The volumetric changes of concrete structures due to the loss of moisture by evaporation is known as concrete shrinkage or shrinkage of concrete. It is a time-dependent deformation which reduces the volume of concrete without the impact of external forces.

Types of Shrinkage in Concrete:

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

- (a) Plastic Shrinkage in concrete
- (b) Drying Shrinkage in concrete
- (c) Autogeneous Shrinkage in concrete
- (d) Carbonation Shrinkage in concrete

The Types of shrinkage are explained as below:

a. Plastic Shrinkage:

Plastic shrinkage is contraction in volume due to water movement from the concrete while still in the plastic state, or before it sets. This movement of water can be during the hydration process or from the environmental conditions leading to evaporation of water that resides on the surface on the wet concrete. So, the more the concrete bleeds, the greater the plastic shrinkage should be. Plastic shrinkage is proportional to cement content and, therefore, inversely proportional to the w/c ratio.

Plastic shrinkage in concrete can be reduced mainly by preventing the rapid loss of water from surface. This can be done by covering the surface with polyethylene sheeting immediately on finishing operation; by fog spray that keeps the surface moist; or by working at night. Use of small quantity of aluminium powder is also suggested to offset the effect of plastic shrinkage. Similarly, expansive cement or shrinkage compensating cement also can be used for controlling the shrinkage during the setting of concrete.

b. Drying Shrinkage:

Just as the hydration of cement is an everlasting process, the drying shrinkage is also an everlasting 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:

Autogeneous shrinkage, also known as “basic shrinkage,” is the shrinkage due to chemical reactions between cement with water, known as hydration, and do not include environmental effects such as temperature and moisture changes. Its magnitude is usually ignored in concretes with w/c more than 0.40.

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 $[\text{Ca}(\text{OH})_2]$ gets converted to calcium carbonate and also some other cement compounds are decomposed. Such a complete decomposition of calcium compound in hydrated cement is chemically possible even at the low pressure of carbon dioxide in normal atmosphere. Carbonation penetrates beyond the exposed surface of concrete very slowly. The rate of penetration of carbon dioxide depends also on the moisture content of the concrete and the relative humidity of the ambient medium. Carbonation is accompanied by an increase in weight of the concrete and by shrinkage.

Carbonation shrinkage is probably caused by the dissolution of crystals of calcium hydroxide and deposition of calcium carbonate in its place. As the new product is less in volume than the product replaced, shrinkage takes place. Carbonation of concrete also results in increased strength and reduced permeability, possibly because water released by carbonation promotes the process of hydration and also calcium carbonate reduces the voids within the cement paste. As the magnitude of carbonation shrinkage is very small when compared to long term drying shrinkage, this aspect is not of much significance

MIX DESIGN

The various factors affecting the choice of concrete mix design are:

1. Compressive strength of concrete

- Concrete compressive strength considered as the most important concrete property. It influences many other describable properties of the hardened concrete.
- The mean compressive strength (fcm) required at a specific age, usually 28 days, determines the nominal water-cement ratio of the mix.
- ISO 456-200, British Standard, and Eurocode utilize the term mean compressive strength which is slightly greater than characteristic compressive strength. However, ACI Code do not use such term.
- Other factors which influences the concrete compressive strength at given time and cured at a specified temperature is compaction degree.
- Concrete compressive strength is inversely proportional to the water-cement ratio.

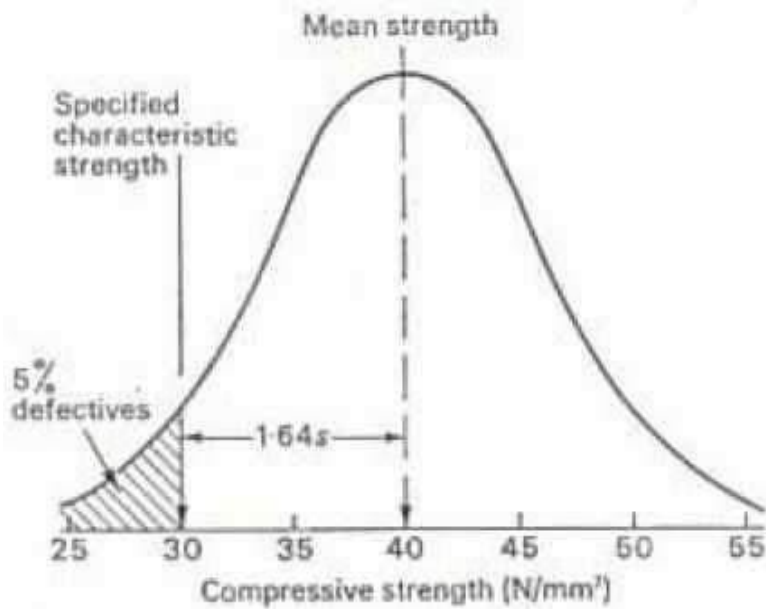


Fig.1: Means compressive strength vs characteristic compressive strength



Fig.2: compressive strength of concrete

2. Workability of concrete

- Concrete workability for satisfactory placement and compaction depends on the size and shape of the section to be concreted, the amount and spacing of reinforcement, and concrete transportation; placement; and compaction technique.
- Additionally, use high workability concrete for the narrow and complicated section with numerous corners or inaccessible parts. This will ensure the achievement of full compaction with a reasonable amount of effort.

- Slump test values used to evaluate concrete workability.
- Slump test values for various reinforced concrete sections ranges from 25 mm to 175mm.

3. Durability of concrete

- The ability of concrete to withstand harmful environment conditions termed as concrete durability.
- 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 utilized water-cement ratio.
- Concrete durability decreases with the increase of w/c ratio.

4. Maximum nominal size of aggregate

- Reinforcement spacing controls maximum aggregate size.
- Aggregate size is inversely proportional to cement requirement for water-cement ratio. This is because workability is directly proportional to size of aggregate
- However, the compressive strength tends to increase with the decrease in size of aggregate. Smaller aggregate size offers greater surface area for bonding with mortar mix that gives higher strength.
- IS 456:2000 and IS 1343:1980 recommends that the nominal size of the aggregate should be as large as possible.
- Finally, in accordance with ACI code, maximum aggregate size shall not exceed minimum reinforcement spacing, bar diameter, or 25mm.



Fig.3: Maximum aggregate size

5. Grading and type of aggregate

- Aggregate grading influences the mix proportions for a specified workability and water-cement ratio.

- The relative proportions between coarse and fine aggregate in concrete mix influence concrete strength.
- Well graded fine and coarse aggregate produce a dense concrete because of the achievement of ultimate packing density.
- If available aggregate, which obtained from natural source, does not confirm to the specified grading, the proportioning of two or more aggregate become essential.
- Additionally, for specific workability and water to cement ratio, type of aggregate affects aggregate to cement ratio.
- Lastly, An important feature of a satisfactory aggregate is the uniformity of the grading that achieved by mixing different size fractions.

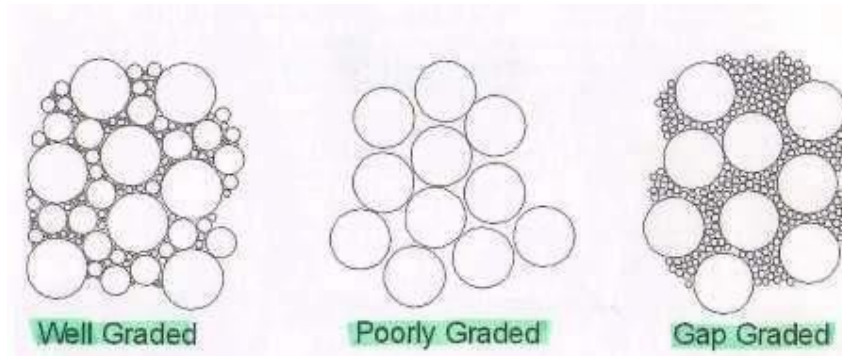


Fig.7: aggregate grading types

6. Quality Control at site

- The degree of control could be evaluated by the variations in test results.
- The variation in strength results from the variations in the properties of the mix ingredients, in addition to lack of control of accuracy in batching, mixing, placing, curing and testing.
- Finally, 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.

ACCEPTANCE CRITERIA FOR DESIGN MIX CONCRETE

The concrete shall be deemed to comply with the strength requirements if:

- a) Every sample has a test strength not less than the characteristic value; or
 - b) The strength of one or more samples though less than the characteristic value, is in each case not less than the greater of :
 - 1) The characteristic strength minus 1.35 times the standard deviation; and

2) 0.80 times the characteristic strength ; and the average strength of all the samples is not less than the characteristic strength plus

$$\text{times} \left[1.65 - \frac{1.65}{\sqrt{\text{No. of samples}}} \right]$$

II. The concrete shall be deemed not to comply with the strength requirements if:

a) The strength of any sample is less than the greater of :

1) the characteristic strength mix is 1.35 times the standard deviation; and

2) 0.80 times the characteristic strength ; or

b) The average strength of all samples is less than the characteristic strength plus

$$\text{times} \left[\frac{\text{the standard deviation}}{1.65} - \frac{1.65}{\sqrt{\text{No. of samples}}} \right]$$

III Concrete which does not meet the strength requirements as specified in I, but has a strength greater than that required by II may, at the discretion of the designer, be accepted as being structurally adequate without further testing.

IV. Concrete of each grade shall be assessed separately.

V Concrete shall be assessed daily for compliance.

VI. Concrete is liable to be rejected if it is porous or honey-combed; its placing has been interrupted without providing a proper construction joint; the reinforcement has been displaced beyond the tolerances specified; or construction tolerances have not been met. However, the hardened concrete may be accepted after carrying out suitable remedial measures to the satisfaction.

VIII. Where the value of the average strength of the tests (preferably 30 tests or 15 tests) is less than

$$\text{shal } f_{ck} + \left\{ 1.65 - \frac{1.65}{\eta} \right\} \times s$$

CONCRETE MIX PROPORTIONING:-

Determination of the proportion of the concrete ingredients such as cement, fine aggregate, coarse aggregate, water and admixtures is called concrete mix. • A proper mix design only can give the specified properties such as workability, strength, permeability and durability with economy.

Methods of Proportioning Concrete

- Arbitrary Method of Proportioning Concrete.
- Fineness Modulus Method of Proportioning Concrete.
- Minimum Void Method.
- Maximum Density Method.
- Water – Cement Ratio Method of Proportioning Concrete.

ARBITRARY METHOD OF PROPORTIONING CONCRETE:-

The general expression for the proportions of cement, sand and coarse aggregate in 1:n:2n by volume.

- 1:1:2 and 1:1.2:2.4 for very high strength
- 1:1.5:3 and 1:2:4 for normal works
- 1:3:6 and 1:4:8 for foundations and mass concrete works.

Recommended mixes of concrete:

The concrete as per IS 456:2000, the grades of concrete lower than M20 are not to be used in RCC work.

M10	1 : 3 : 6
M15	1 : 2 : 4
M20	1 : 1.5 : 3
M25	1 : 1 : 2

Fineness Modulus Method of Proportioning Concrete:-

The term fineness modulus is used to indicate an index number which is roughly proportional to the average size of the particle in the entire quantity of aggregates.

The fineness modulus is obtained by adding the percentage of weight of the material retained on the following sieve and divided by 100.

The coarser the aggregates, the higher the fineness modulus.

Sieve is adopted for:

All aggregates : 80 mm, 40 mm, 20 mm, 10 mm, and Nos. 480, 240, 120, 60, 30 and 15.

Coarse aggregates : mm, 40 mm, 20 mm, 10 mm, and No. 480.

Fine aggregates : Nos. 480, 240, 120, 60, 30 and 15.

Proportion of the fine aggregate to the combined aggregate by weight

$$R = \frac{P_2 - P}{P - P_1} \times 100$$

Where, P = desired fineness modulus for a concrete mix of fine and coarse aggregates. P_1 = fineness modulus of fine aggregate

P_2 = fineness modulus of coarse aggregate.

Minimum Void Method:-

It does not give satisfactory result.

The quantity of sand used should be such that it completely fills the voids of coarse aggregate. Similarly, the quantity of cement used shown such that it fills the voids of sand, so that a dense mix the minimum voids is obtained.

In actual practice, the quantity of fine aggregate used in the mix is about 10% more than the voids in the coarse aggregate and the quantity of cement is kept as about 15% more than the voids in the fine aggregate.

Maximum Density Method:

This method is not very Popular.

$$P = 100 \left(\frac{d}{D} \right)^{1/2}$$

It is determined by the formula as aggregate (i.e. coarse aggregate)

Where, D = maximum size of

P = percentage of material finer than diameter d (by weight) d = maximum size of fine aggregate.

A box is filled with varying proportions of fine and coarse aggregates. The proportion which gives heaviest weight is then adopted.

Water – Cement Ratio Method of Proportioning Concrete:-

According to the water – cement ratio law given by Abram as a result of many experiments, the strength of well compacted concrete with good workability is dependent on the ratio.

- The lower water content produces stiff paste having greater binding property and hence the lowering the water-cement ratio within certain limits results in the increased strength.
 - Similarly, the higher water content increases the workability, but lower the strength of concrete.
 - The optimum water-cement ratio for the concrete of required compressive strength is decided from graphs and expressions developed from various experiments.
 - Amount of water less than the optimum water decreases the strength and about 10% less may be insufficient to ensure complete setting of cement. An increase of 10% above the optimum may decrease the strength approximately by 15% while an increase in 50% may decrease the strength to one-half.
 - According to Abram's Law water-cement law, lesser the water-cement ratio in a workable mix greater will be the strength.
 - If water cement ratio is less than 0.4 to 0.5, complete hydration will not be secured. Some practical values of water cement ratio for structure reinforced concrete
 - 0.45 for 1 : 1 : 2 concrete
 - 0.5 for 1 : 1.5 : 3 concrete
 - 0.5 to 0.6 for 1 : 2 : 4 concrete.
- Concrete vibrated by efficient mechanical vibrators require less water cement ratio, and hence have more strength.

Thumb Rules for deciding the quantity of water in concrete: Weight of water = 28% of the weight of cement + 4% of the weight of total aggregate

(ii) Weight of water = 30% of the weight of cement + 5% of the weight of total aggregate.

BIS METHOD OF MIX DESIGN:-

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.

Procedure for concrete mix design requires following step by step process:

1. Calculation of target strength of concrete
2. Selection of water-cement ratio
3. Determination of aggregate air content

4. Selection of water content for concrete
5. Selection of cement content for concrete
6. Calculation of aggregate ratio
7. Calculation of aggregate content for concrete
8. Trial mixes for testing concrete mix design strength

Step 1: Calculation of Target Strength of Concrete:-

Target strength is denoted by f_t which is obtained by characteristic compressive strength of concrete at 28 days (f_{ck}) and value of standard deviation (s)

$$f_t = f_{ck} + 1.65 s$$

Standard deviation can be taken from below

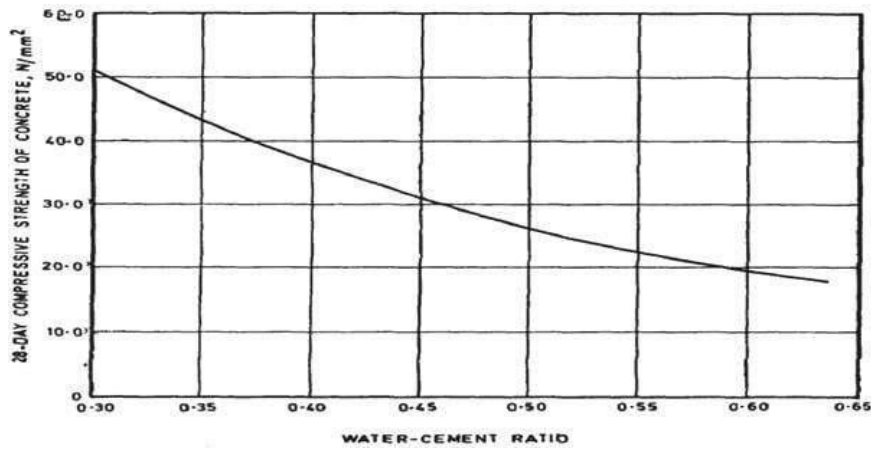
table

Grade of concrete	Standard deviation (N/mm ²)
M10	3.5
M15	3.5
M20	4.0
M25	4.0
M30	5.0
M35	5.0
M40	5.0
M45	5.0
M50	5.0

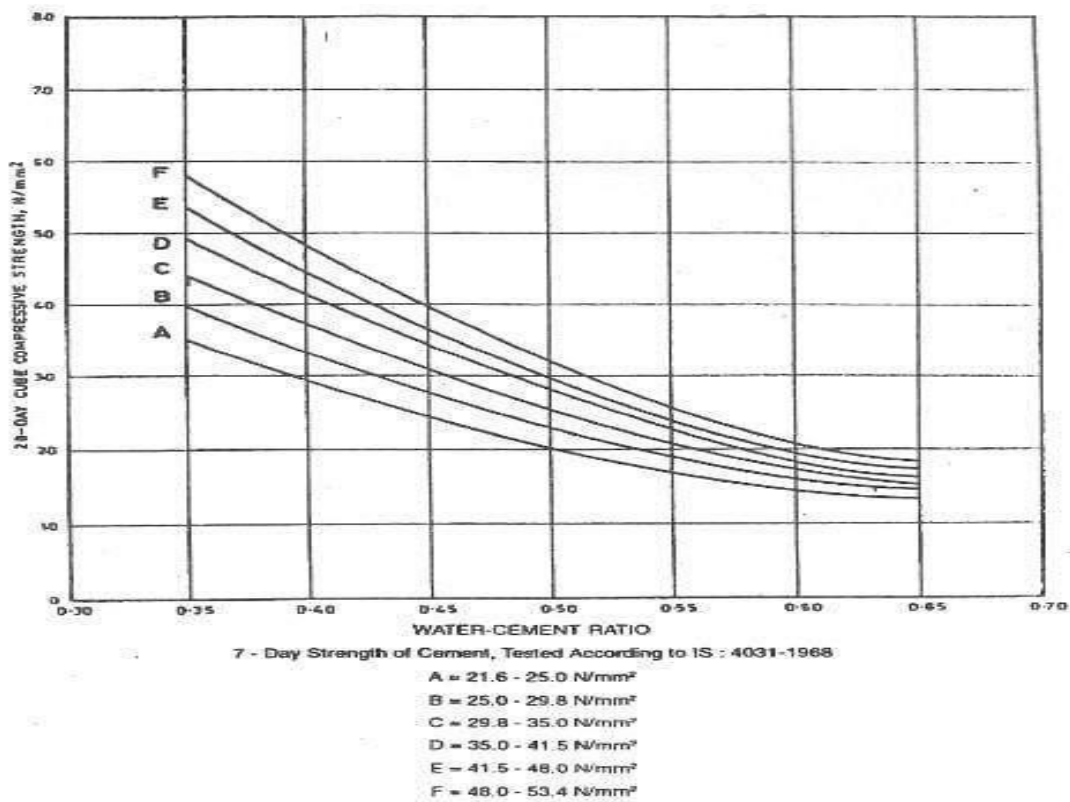
Step 2: Selection of Water-Cement Ratio:-

Ratio of the weight of water to weight of cement in the concrete mix is water-cement ratio. It is the important consideration in concrete mix design to make the concrete workable.

Water cement ratio is selected from the below curve for 28 days characteristic compressive strength of concrete.



Similarly, we can determine the water-cement ration from the 7-day concrete strength, the curves are divided on the basis of strength from water cement ratio is decided. Which is observed from the below graph.



Step 3: Determination of Aggregate Air content:-

Nominal maximum size of aggregate	Air content (% of volume of concrete)
10mm	5%
20mm	2%
40mm	1%

Air content in the concrete mix is determined by the nominal maximum size of aggregate used. Below table will give the entrapped air content in percentage of volume of concrete.

Step 4: Selection of Water Content for Concrete:-

Select the water content which is useful to get required workability with the help of nominal maximum size of aggregate as given in below table. The table given below is used when only angular shaped aggregates are used in concrete as well as the slump should be 25 to 50mm.

Nominal maximum size of aggregate	Maximum water content
10mm	208
20mm	186
If the shape of aggregate or slump value is differing from above, then some adjustments are required	
40mm	165

SPECIAL CONCRETE

LIGHT WEIGHT CONCRETE:-

Light weight concrete can be defined as a type of concrete which includes an expanding agent in that it increases the volume of the mixture while giving additional qualities such as liability and lessened the dead weight. It is lighter than the conventional concrete

The material unit cost of lightweight concrete is typically higher than that of normal-weight concrete, but the unit cost usually is more than offset by the overall reduction in concrete volume and steel tonnage for the structural system.

The benefits of using lightweight aggregate concrete include:

- Reduction in dead loads making savings in foundations and reinforcement.
- Improved thermal properties.
- Improved fire resistance.
- Savings in transporting and handling precast units on site.
- Reduction in formwork and propping.

Disadvantages:-

- It is very sensitive with water content in the mixture.
- It is difficult to place and finish because of the porosity and angularity of the aggregate.
- Mixing time is longer than conventional concrete to assure proper mixing.

Light weight aggregate concrete:-

Light weight aggregate is a type of coarse aggregate that is used in the production of lightweight concrete products such as concrete block, structural concrete, and pavement. The expanded material has properties similar to natural aggregate, but is less dense and therefore yields a lighter concrete product.

Foam concrete, also known as Lightweight Cellular Concrete (LCC) or Low Density Cellular Concrete (LDCC) is defined as a cement-based slurry, with a minimum of 20% (per volume) foam entrained into the plastic mortar.

The concrete has a minimum 28-day compressive strength of 2500 psi (17 MPa), an equilibrium density between 70 and 120 lb/ft³ (1120 and 1920 kg/m³), and consists entirely of lightweight aggregate or a combination of lightweight and normal-density aggregate.

CELLULAR CONCRETE:- Cellular concrete is a lightweight cement-based material, containing many gas bubbles evenly distributed in the volume, produced by blending and maturing of a mixture of cement, filler, water, and agent generating cells. By the method of generating the air or gas cells there exist foam concrete and gas concrete.

cellular concrete is used in building and construction applications such as roof decks and floor decks, and geotechnical applications such as annular space filling in slip lining and void fill abandonment. Cellular concrete can also be found in architectural and precast applications. cellular concrete is used in building and construction applications such as roof decks and floor decks, and geotechnical applications such as annular space filling in slip lining and void fill abandonment. Cellular concrete can also be found in architectural and precast applications.

Material Used in Cellular Concrete:-

The materials used in cellular concrete which reduce the density of concrete are :

1. Cement

Cellular lightweight concrete is a homogeneous combination of Portland cement, cement-silica, cement-pozzolana, lime-pozzolana; lime-silica pastes having identical cell structure obtained using gas-forming chemicals of foaming agents at measured levels.

2. Fly Ash

As fly ash is a by-product and its disposal is very expensive. It is used in the preparation of cellular light-weight concrete. It is one of the key ingredients which resolve the issue of disposal and at the same time, it's very economical making it environmentally friendly.

3. Foam

The main constituent of the raw material of foam that is used in the production of cellular concrete is Genfil and its organic substance. The size of the bubbles differs from around 0.1 to 1.5 mm in diameter. The foam generator is employed to produce stable foam by using an appropriate agent.

Reference Codes on Cellular Concrete

1. ASTM C 869 – “Standard Specification for Foaming Agents Used in Making Preformed Foam for Cellular Concrete”
2. ASTM C 796 – “Standard Test Method for Foaming Agents for use in Producing Cellular Concrete using Preformed Foam”
3. ASTM C 495 – “Standard Test Method for Compressive Strength of Lightweight Insulating Concrete”

Types of Cellular Concrete based on Density

Cellular concrete is differentiated into 3 types based on the range of density, which is produced for different purpose.

1. High Density Cellular Concrete

This is a structural grade concrete having the density ranging from 1200 kg/m³ to 1800 kg/m³. It is used in the construction of load-bearing walls, partition walls and in the production of pre-cast blocks for load-bearing brickwork.

2. Medium Density Cellular Concrete

The density range of this cellular concrete is 800-1000 kg/m³. The major use of this type of cellular concrete is found in the manufacturing pre-cast blocks for non-load-bearing brickwork.

3. Light Density Cellular Concrete

Light density cellular concrete has a density in the range of 400 –600 kg/m³. LDCC is ideal for thermal and sound insulations. They act as a resistance against fire accidents, termite and moisture absorbent.

They have also proved to be a better substitute than glass wool, wood wool and thermocol.

Advantages of Cellular Concrete:

1. Lightweight

The low weight property of cellular concrete has a great advantage on building dead loads and craning works.

2. Fire Resistance

The air pockets formed acts as a barrier for fire. The structure made of cellular concrete is non-combustible and can endure fire breakout for hours.

3. Thermal Insulation

Cellular concrete acts a perfect thermal insulator.

4. Acoustical Insulation

The low density increases acoustical insulation.

5. Environmental Friendly

Fly-ash based cellular lightweight concrete is suitable for surrounding because fly-ash is one of the by-products of industrial waste.

6. Cost-Efficient

Cost of the material used is concrete is reduced as the foam is introduced into the concrete. Secondly, the use of industrial waste such as fly-ash saves a considerable amount of investment on cement products.

7. Other Advantages

Cellular light-weight concrete is also termite-proof and resistant towards freezing issues.

NON-FINES CONCRETE:-

HIGH DENSITY CONCRETE:-

High density concrete is a concrete having a density in the range of 6000 to 6400 kg/cum.

High density concrete is also known as Heavy weight concrete. High density concrete is mainly used for the purpose of radiation shielding, for counterweights and other uses where high density is required.

The high density concrete has a better shielding property, so that it can protect harmful radiations like X-rays, gamma rays, and neutrons.

High density aggregates are used to achieve heavy weight concrete. Some of the high density aggregates are barite, ferrophosphorus, limonite, hematite, magnetite, goethite, steel punching, and steel shots. The point to remember is that in order to achieve this type of concrete, high fixed water content is required.

The selection of the above mentioned aggregates mainly depend upon the physical properties like bulk density, specific gravity, availability of materials, and its expenses. In order to achieve workability, high density the aggregates should be free from dirt, oil or grease stains and other foreign matter. Or else, it will retard the hydration process and the effective bonding of particles. Some of the boron additions like colemanite, borocalcite are used in the preparation of concrete to improve the shielding properties. These additions may affect the setting time of concrete so, trial mixes should be made and tested depending upon the suitability.

FIBRE REINFORCED CONCRETE:-

Fibre Reinforced Concrete can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibres.

Fibre is a small piece of reinforcing material possessing certain characteristics properties. They can be circular or flat. The fibre is often described by a convenient parameter called "aspect ratio". The aspect ratio of the fibre is the ratio of its length to its diameter. Typical aspect ratio ranges from 30 to 150.

Fibre-reinforcement is mainly used in shotcrete, but can also be used in normal concrete. Fibre-reinforced normal concrete are mostly used for on-ground floors and pavements, but can be considered for a wide range of construction parts (beams, piers, foundations etc) either alone or with hand-tied rebars.

NECESSITY OF FIBER REINFORCED CONCRETE:-

- It increases the tensile strength of the concrete.
- It reduces the air voids and water voids the inherent porosity of gel.
- It increases the durability of the concrete.
- Fibres such as graphite and glass have excellent resistance to creep, while the same is not true for most resins. Therefore, the orientation and volume of fibres have a significant influence on the creep performance of rebars/tendons.
- Reinforced concrete itself is a composite material, where the reinforcement acts as the strengthening fibre and the concrete as the matrix. It is therefore imperative that the behaviour under thermal stresses for the two materials be similar so that the differential deformations of concrete and the reinforcement are minimized.
- It has been recognized that the addition of small, closely spaced and uniformly dispersed fibres to concrete would act as crack arrester and would substantially improve its static and dynamic properties.

Polymer concretes

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

COMPOSITION:-

In polymer concrete, thermoplastic polymers are used, but more typically thermosetting resins are used as the principal polymer component due to their high thermal stability and resistance to a wide variety of chemicals. Polymer concrete is also composed of aggregates that include silica, quartz, granite, limestone, and other high quality material. The aggregate must be of good quality, free of dust and other debris, and dry. Failure to fulfil 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 corrosion resistance and low permeability 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.

PROPERTIES:-

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

The binder is more expensive than cement

Significantly greater tensile strength than unreinforced Portland concrete (since plastic is 'stickier' than cement and has reasonable tensile strength)

Similar or greater compressive strength to Portland concrete Much faster curing

Good adhesion to most surfaces, including to reinforcements Good long-term durability with respect to freeze and thaw cycles Low permeability to water and aggressive solutions

Good chemical resistance

Good resistance against corrosion

Lighter weight (slightly less dense than traditional concrete, depending on the resin content of the mix)

May be vibrated to fill voids in forms

Allows use of regular form-release agents (in some applications) Dielectric

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

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

Polymers are added to the concrete mixes either in the form of an aqueous emulsion or in a dispersed form. This is to improve the following properties of concrete:

1. The extensibility and the tensile strength of the concrete structure
2. The impact resistance
3. The Abrasion resistance
4. The durability and the resistance to the aggressive fluids
5. The bond between the old and the new concrete

The polymer modified cement concrete is a composite that is obtained by the incorporation of a polymeric material into the concrete. This is carried out during the mixing stage. The polymers that are incorporated at this stage should in no way interfere with the hydration process.

Types of Polymer Modified Concrete (PMC)

Based on the type of the modifier used, polymer modified concrete can be classified into the following types:

1. Latex-Modified Cement Concrete

2. Pre-Polymer Modified Cement Concrete

Latex-Modified Cement Concrete

The lattices are white milk like suspensions that consist of very small sized polymer particles, that are suspended in water with the help of emulsifiers and stabilizing agents. It contains about 50% of polymer solid by mass.

Both elastomeric and glassy polymers have been employed in the lattices for modifying cement concrete. These impart high modulus of elasticity, higher strength and low rate of corrosion of the reinforcement.

The latex admixtures can be stored in an adequate exposure that helps the mixture to be protected against the freezing and temperature exposures.

If the mixture stored drum is exposed to sunlight, it has to be properly covered with a suitable insulating blanket. The enclosed temperature to be maintained must be less than 85F.

The natural rubber latex, acrylonitrile-butadiene, neoprene and rubber latex are some of the commonly used elastomeric latex. The glass polymers have a greater modulus of elasticity, strength and they undergo a brittle type of failure.

The common examples of the same are polyvinylidene chloride, acrylic polymers, polyvinyl acetate and styrene butadiene copolymer latex. The polyvinylidene copolymer is used in unreinforced concrete applications due to the presence of residual chlorine that causes the corrosion of reinforcement.

Moist curing of composite for a period of one to seven days forms the optimum curing temperature. This is later followed by a dry curing. At the 28 days of curing, the latex modified concrete would have gained its final strength.

Prepolymers-Modified Cement Concrete

The polyester-styrene based system, epoxy system and the furan system etc. are used for this. The strength improvement of this type of PMC is of the order of 50-100% over the conventional concrete.

Its adhesion property is good and has the improved durability properties. The tensile strength and the modulus of rupture are more than twice those of the conventional concrete. The formation of the micro-cracking is less in the case of pre-polymer-modified cement concrete.

There is lower water cement ratio and the filling of pores within the pre polymer modified concrete which will help in improving the durability of the concrete compared with the conventional concrete. But the cost of the polymer is not accounted in the strength gain of the polymer modified concrete.

Properties of Polymer Modified Concrete

The properties of Polymer modified concrete are explained below:

- The addition of polymers makes the concrete mix to become more workable. This can hence reduce the amount of water that is added to the concrete mix.
- The crushing strength of the concrete is increased using the polymer in concrete. This is because the polymer reduces the water cement ratio which in turn increase the crushing strength.
- The bond between the aggregate and the matrix is improved.
- The polymer modification increases the flexural strength of the concrete.
- The polymer modified concrete consist of at least 3 % more amount of entrained air than the plain concrete. This additional amount of entrained air will reduce the modulus of elasticity of the concrete (PMC).
- The polymer addition increases the setting time of concrete.
- The resistance of the concrete against abrasion is increased using the polymer.
- Freezing and thawing resistance of the concrete structure is improved by polymer modification.
- The penetration of chlorine ions and other deleterious materials is restricted. The PMC gain higher resistance against such undesirable effects.
- The PMC gains superior shear bond strength.
- The ductility property of the polymer modified concrete is more compared with the conventional concrete.
- These gain a superior tensile and flexural strength compared to the conventional concrete.

Applications of Polymer Modified Concrete:-

- The polymer modified concrete can be used in the repair and the rehabilitation of old damaged concrete.
 - The floor construction in frozen – food factories gains great application. This is because of the higher freeze and thaw resistance of PMCs.
 - For floor construction of factories were chances of the splitting of chemicals and oils more prone to happen.
- For the preparation of steel bridge and ship decks surfaces.
- For the concrete structure that is more subjected to large doses of de-icing salts.

HIGH PERFORMANCE CONCRETE:-

- High performance concrete is a concrete mixture, which possess high durability and high strength when compared to conventional concrete.
- This concrete contains one or more of cementitious materials such as fly ash, Silica fume or ground granulated blast furnace slag and usually a super plasticizer.
- The term ‘high performance’ is somewhat pretentious because the essential feature of this concrete is that it’s ingredients and proportions are specifically chosen so as to

have particularly appropriate properties for the expected use of the structure such as high strength and low permeability.

- Hence High performance concrete is not a special type of concrete. It comprises of the same materials as that of the conventional cement concrete. The use of some mineral and chemical admixtures like Silica fume and Super plasticizer enhance the strength, durability and workability qualities to a very high extent.
- High Performance concrete works out to be economical, even though it's initial cost is higher than that of conventional concrete because the use of High Performance concrete in construction enhances the service life of the structure and the structure suffers less damage which would reduce overall costs.
- Concrete is a durable and versatile construction material. It is not only
- Strong, economical and takes the shape of the form in which it is placed, but it is also aesthetically satisfying. However experience has shown that concrete is vulnerable to deterioration, unless precautionary measures are taken during the design and production. For this we need to understand the influence of components on the behaviour of concrete and to produce a concrete mix within closely controlled tolerances

The conventional Portland cement concrete is found deficient in respect of :

- Durability in severe environs (shorter service life and frequent maintenance)
- Time of construction (slower gain of strength)
- Energy absorption capacity (for earthquake resistant structures)
- Repair and retrofitting jobs.

Hence it has been increasingly realized that besides strength, there are other equally important criteria such as durability, workability and toughness. And hence we talk about 'High performance concrete' where performance requirements can be different than high strength and can vary from application to application.

SELF COMPACTING CONCRETE (SCC):-

Self compacting concrete (SCC) can be defined as fresh concrete that flows under its own weight and does not require external vibration to undergo compaction. It is used in the construction where it is hard to use vibrators for consolidation of concrete.

Materials Used for Self Compacting Concrete

The main ingredients used in design of self compacting concrete are:

1. Cement

Ordinary Portland cement either 43 or 53 grade cement can be used.

2. Aggregates

The size of the aggregates used for SCC design is limited to 20mm. If the reinforcement employed for the structure is congested, the aggregate size used can be in the range 10 to 12mm. Well graded aggregates either round or cubical shape are a best choice.

The fine aggregates used in SCC can be either natural aggregates or manufactured aggregates (M- Sand) with a uniform grade. The fine aggregates with particle size less than 0.125mm are generally employed.

3. Water

The quality of water used is same that followed for reinforced concrete and prestressed concrete construction.

4. Mineral Admixtures

The mineral admixtures used can vary based on the mix design and properties required. Mentioned below are the different mineral admixtures that can be used and their respective properties they provide.

Ground Granulated Blast Furnace Slag (GGBS): The use of GGBS helps to improve the rheological properties of the self compacting concrete.

Fly ash: The fine fly ash particles help to improve the filling of the internal concrete matrix with fewer pores. This improves the quality and durability of the SCC structures.

Silica Fumes: The use of silica fumes helps to increase the mechanical properties of the self compacting concrete structure.

Stone Powder: The use of stone powder in SCC is used to improve the powder content of the mix.

5. Chemical Admixtures

New generation super plasticizers are commonly used in SCC mix design. In order to improve the freeze and thaw resistance of the concrete structure, air entraining agents are used. To control the setting time, retarders are employed.

Tests and Properties of Self Compacting Concrete

The requirements of the self compacting concrete are achieved by the properties in its fresh state. The three main properties of SCC are:

1. **Filling Ability:** This property of the concrete is the ability to flow under its own weight without any vibration provided intentionally.
2. **Passing Ability:** This property is the ability of the concrete to maintain its homogeneity.
3. **Segregation resistance:** This is the resistance of the concrete not to undergo segregation when it flows during the self compaction process.
Different tests are conducted to determine the above mentioned properties of Self compacting concrete. The tests conducted for Self compacting concrete can be categorized into three categories:

1. Filling Ability Tests
2. Passing Ability Tests
3. Segregation Resistance Test

Filling Ability Tests	Passing Ability Tests	Segregation Resistance Tests
Slump flow test	L-Box Test	V- funnel test at T5 minutes
T50cm Slump Flow	J- ring test	GTM screen stability Tests
Orimet	U- Box Test	
V-funnel Test	Fill – Box Test	

Advantages of Self Compacting Concrete

The main advantages of self compacting concrete are:

1. The permeability of the concrete structure is decreased
2. SCC enables freedom in designing concrete structures
3. The SCC construction is faster
4. The problems associated with vibration is eliminated
5. The concrete is placed with ease, which results in large cost saving
6. The quality of the construction is increase
7. The durability and reliability of the concrete structure is high compared to normal concrete structures
8. Noise from vibration is reduced. This also reduce the hand arm vibration syndrome issues

Disadvantages of Self Compacting Concrete

SCC construction face the following limitations:

1. There is no globally accepted test standard to undergo SCC mix design
2. The cost of construction is costlier than the conventional concrete construction
3. The use of designed mix will require more trial batches and lab tests
4. The measurement and monitoring must be more precise.
5. The material selection for SCC is more stringent

Applications of Self Compacting Concrete

The major applications of self compacting concrete are:

1. Construction of structures with complicated reinforcement
2. SCC is used for repairs, restoration and renewal construction
3. Highly stable and durable retaining walls are constructed with the help of SCC
4. SCC is employed in the construction of raft and pile foundation

