4.3 DETERMINATION OF STRENGTH PROPERTIES OF HARDENED CONCRETE

Properties Of Hardened Concrete

1. Strength

(A) Compressive Strength

(B) Tensile

(C) Shear Or Flexural

2. Durability

3. Permeability

4. Dimensional Stability

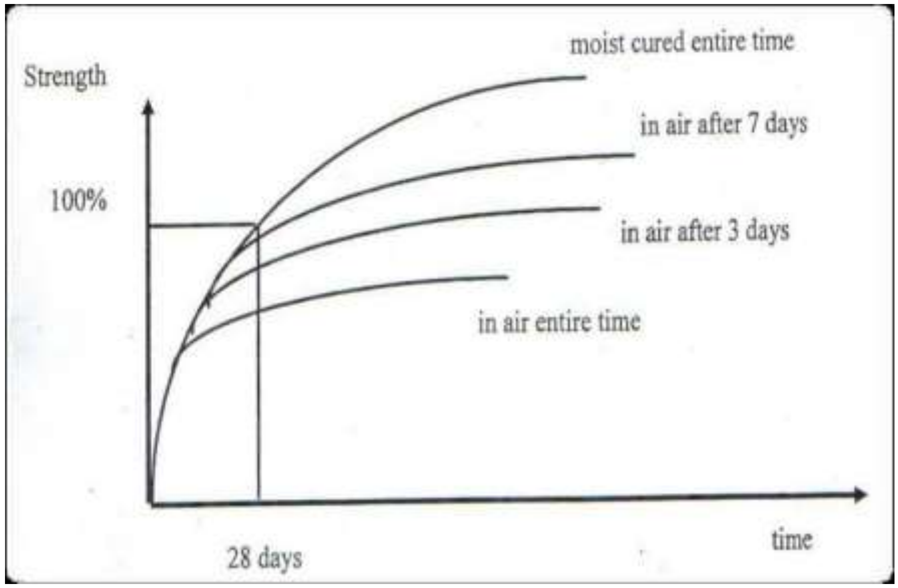
5. Creep

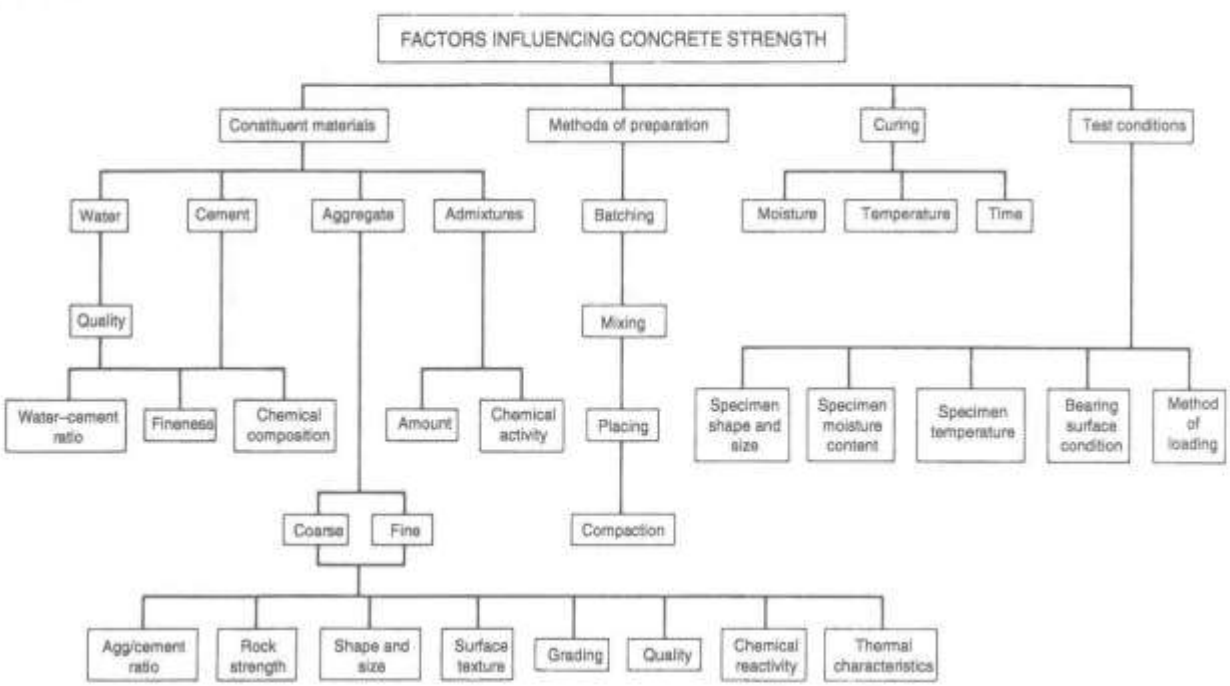
6. Shrinkage

7. Modulus Of Elasticity

1. Strength

- Strength of concrete is defined as the max stress it can resist or the max it can carry.
- Cubes, cylinders and prisms are the 3 type of compression test specimens.
- Flexural tensile test is used to estimate the load at which the concrete members may crack.
- Compressive Strength taken as the maximum compression load it can carry per unit area.


Strength
100%
moist cured entire time
in air after 7 days
in air after 3 days
in air entire time
28 days
time


FACTORS INFLUENCING CONCRETE STRENGTH
Constituent materials
Methods of preparation
Curing
Test conditions
Water
Cement
Aggregate
Admixtures
Batching
Moisture
Temperature
Time
Quality
Mixing
Water-cement ratio
Fineness
Chemical composition
Amount
Chemical activity
Placing
Specimen shape and size
Specimen moisture content
Specimen temperature
Bearing surface condition
Method of loading
Coarse
Fine
Compaction
Agg/cement ratio
Rock strength
Shape and size
Surface texture
Grading
Quality
Chemical reactivity
Thermal characteristics

- Many destructive and non-destructive tests are conducted on hardened concrete to measure their properties such as strength, permeability and durability;

Destructive testing
(Specimen is broken down)

- **Compressive strength test**
- **Flexural Strength test**
- **Splitting tensile test**
- **Modulus of elasticity**
- Pull out test etc.

Non-Destructive testing
(Specimen is not broken down)

- Ultrasonic pulse velocity

– Before starting these tests some of the points should be considered,

- Concrete mix should be uniform and well compacted
- Curing should be proper
- At least three specimens are needed for a single test and average value of these three specimens is taken.

Each specimen test result should not exceed 5% of the result of other specimens, if exceeded it indicates the poor mix of concrete.

FACTOR INFLUENCING THE STRENGTH OF CONCRETE

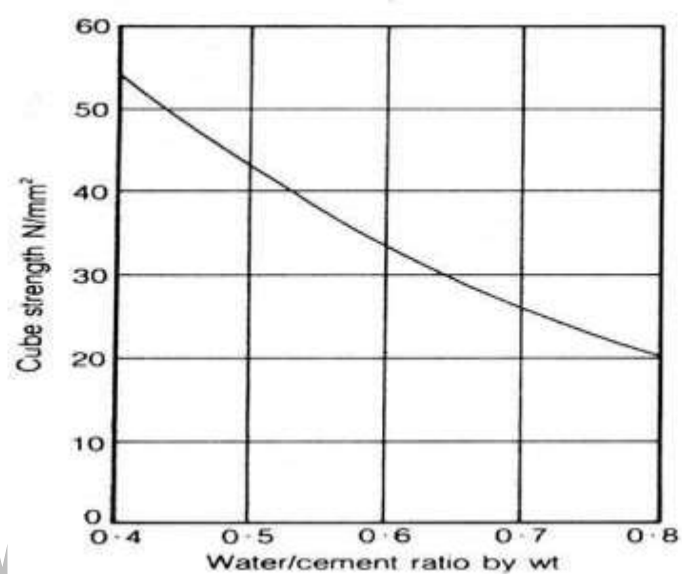
1. Influence of the constituent materials.

a) Cement

- Fineness of cement increase strength.
- Chemical composition.
- Type of cement (eg. RHPC, SRPC, LHPC).

b) Water

- Water cement ratio (w/c) required for hydration process.
- The lower w/c, the greater is the compressive strength and vice versa.



c) Aggregate

- Bond strength between aggregate influence by surface texture, shape and cleanliness.

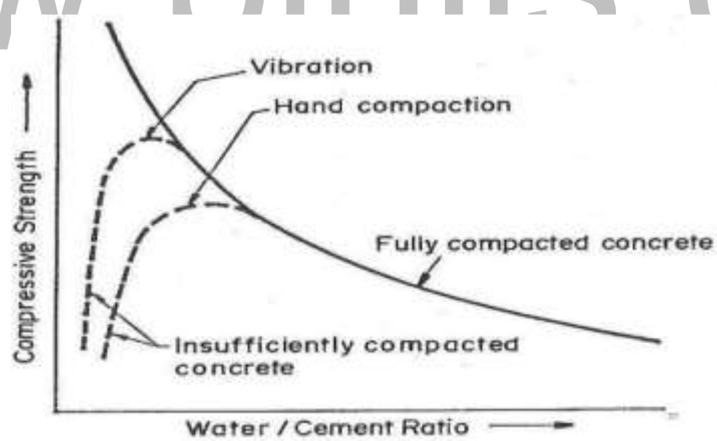
- The compressive strength of concrete tends to increase with the decrease in the size of coarse aggregate. This due to the facts that smaller size aggregates provide larger surface area for bonding with the mortar matrix.

- Aggregate surface roughness has a considerable effect on bond strength (greater the roughness, higher is the bond strength) due to improvement in mechanical interlocking.

- **d) Admixture**
- Effect of particular admixture (eg. accelerator, retarder, plasticizer etc.) depend on the precise nature of the admixtures themselves.

2. Degree of Compaction

- Proper compaction increase strength.
- When the concrete compacts, it has a very low porosity, thus result in a very high strength.
- The increase in the strength of concrete is probably influenced by the volume of voids in concrete i.e. entrapped air, capillary pores, gel pores or entrained air.



Influence of curing

- Curing is used for promoting the hydration of cement and consists of a control of temperature and moisture movement from and into the concrete.
- The longer period of curing, the greater its final strength.

- Early-age: ages less than 7 days
- Later-age: ages exceeding 28 days.

Influence of test conditions

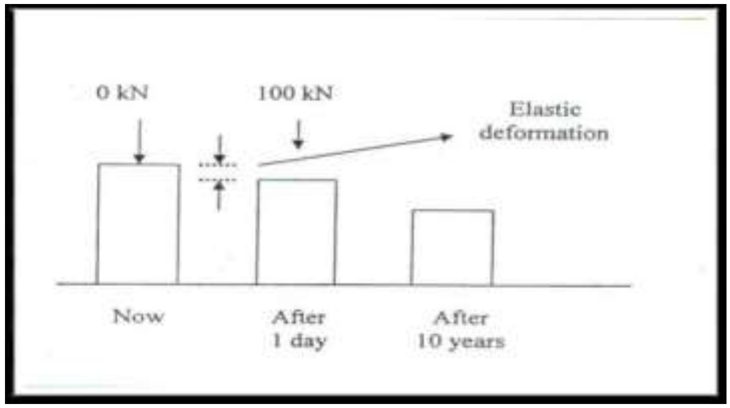
- Specimen shape and size – cube, cylinder and square prism.
- Specimen moisture content and temperature.
- Method of loading.

DEFORMATION UNDER LOAD

- It is a stress strain relationship under normal loading and under sustained loading.
- Under normal loading: the first effect of applying a load to concrete is to produce an elastic deformation i.e. as the load increases deformation increases.
- Under sustained loading: the continue application of stress causes a slow deformation known as creep. The increase of deformation is not proportional , as the time passes the deformation is lesser.

ELASTIC DEFORMATION:

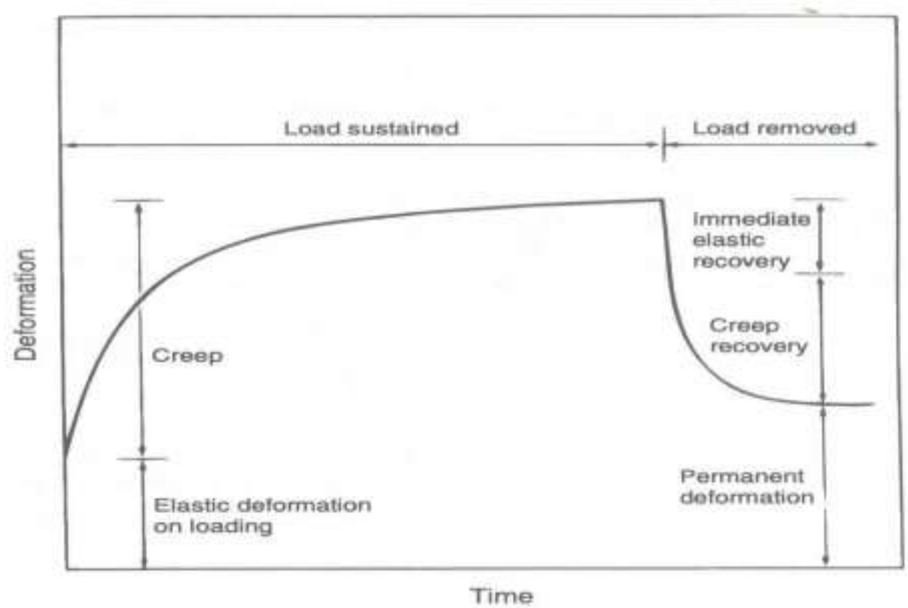
- When the applied load is released, the concrete does not fully recover its original shape.
- Under repeated loading and unloading, the deformation at a given load level increases.



MODULUS OF ELASTICITY

- Defined as the ratio of load per unit area (stress) to the elastic deformation per unit length (strain).
- The modulus of elasticity for most concretes at 28 days, ranges from 15 – 40 kN/mm^2.

$$E = \frac{\text{Stress}}{\text{Strain}} \quad \frac{\sigma}{\varepsilon}$$



Durability

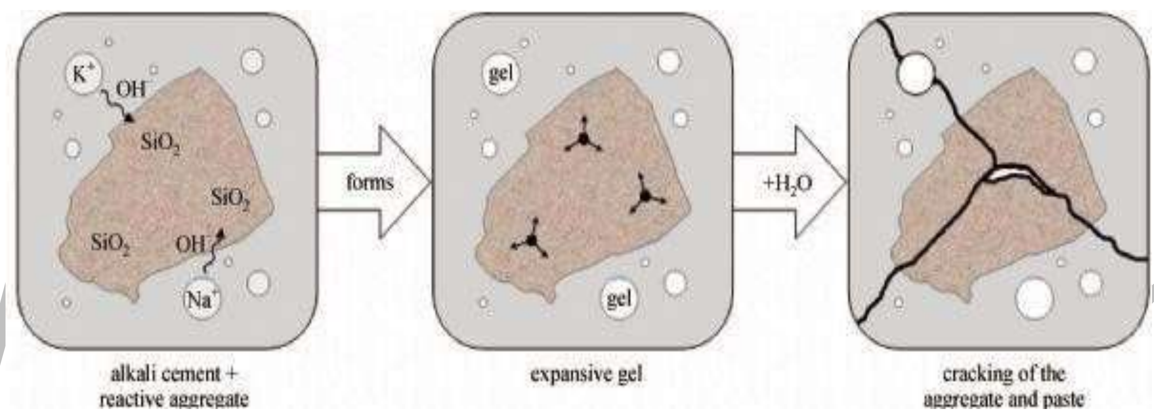
- Defined as its resistance to deterioration processes that may occur as a result of interaction with its environment (external) or between the constituent materials or their reaction with contaminants present (internal).
- Ability to with stand the damaging effects of the environment over a long period of time.
- The absence of durability maybe caused either by the environment to which the concrete is exposed i.e. external or internal causes.

Internal causes

- The alkali-aggregate reaction, volume changes due to the differences in thermal properties of aggregate and cement paste and the permeability of the concrete.

External causes

- physical, chemical and mechanical
- weathering, occurrence of extreme temperature, abrasion, electrolytic action.
- The common forms of chemical attack : leaching out of cement and action of sulphates



Permeability

- ➢ Concrete has a tendency to be porous due to the presence of voids formed during or after placing.
- ➢ Penetration by substance may adversely affect durability e.g. $Ca(OH)_2$ leaches out.
- ➢ Ingress of air and moisture resulting in corrosion.
- ➢ Important with regards to water tightness of liquid retaining structure.
- ➢ To produce concrete of low permeability, full compaction & proper curing is essential.

- Low permeability is important in increasing resistant to frost action and chemical attack and in protecting embedded steel against corrosion.
- The permeability of cement paste varies with the age of concrete or with progress of hydration.
- With age, the permeability decreases because gel gradually fill the original water filled space.
- For the same w/c ratio, the permeability of paste with coarser cement particles is higher than those with finer cement.
- In general, the higher the strength of cement paste, the lower will the permeability.

Factors influencing permeability are:

i. W/C Ratio
ii. Curing
iii. Method of compaction
iv. Workability
v. Soundness & porosity of the aggregate
vi. Age (permeability decrease with age)
vii. Grading of aggregate
viii. Type of structure

Shrinkage

- Caused by the settlement of solids and the loss of free water from the plastic concrete (plastic shrinkage), by the chemical combination of cement with water and by the drying of concrete (drying shrinkage).
- The shrinkage is dependent on the amount of drying that can take place.

Influenced by the humidity and temperature of the surrounding air, the rate of air flow over the surface and the proportion of the surface area to volume of concrete

2 types of shrinkage:

a) Plastic Shrinkage

- Shrinkage which takes place before concrete has set.
- Occurs during the first few hours after fresh concrete is placed.
- During this period, moisture may evaporate faster from the concrete surface than it is replaced by bleed water from lower layers of the concrete mass.

Plastic cracking (Plastic Shrinkage Cracking) is cracking that occurs in the surface of the fresh concrete soon after it is placed and while it is still plastic.

b) Drying Shrinkage

- When a hardened concrete, cured in water, is allowed to dry it first loses water is drawn out of its cement gel.
- After an initial high rate of drying shrinkage concrete continues to shrink for a long period of time but at a continuously decreasing rate.

Factors affecting Shrinkage are:

1. ***Aggregate*** -Concrete with higher aggregate content exhibits smaller shrinkage. Concrete with aggregates of higher modulus of elasticity or of rougher surfaces is more resistant to the shrinkage process.
2. ***Water-cement ratio*** - The higher the W/C ratio is, the higher the shrinkage. As W/C increases, paste strength and stiffness decrease; and as water content increases, shrinkage potential increases.
3. ***Member size*** - Shrinkage decrease with an increase in the volume of the concrete member. However, the duration of shrinkage is longer for larger members since more time is needed for shrinkage effects to reach the interior regions.
4. ***Medium ambient conditions*** - The rate of shrinkage is lower at higher values of relative humidity. Shrinkage becomes stabilized at low temperatures.
5. ***Admixtures*** - effect varies from admixture to admixture. Any material which substantially changes the pore structure of the paste will affect the shrinkage characteristics of the concrete. In general, as pore refinement is enhanced, shrinkage is increased.

Strength of concrete

- The strength of a concrete specimen prepared, cured and tested under specified conditions at a given age depends on:

    1. w/c ratio
    2. Degree of compaction

        - Compressive Strength is determined by loading properly prepared and cured cubic, cylindrical or prismatic specimens under compression.

Permeability is important because:

1. The penetration of some aggressive solution may result in leaching out of $Ca(OH)_2$ which adversely affects the durability of concrete.
2. The moisture penetration depends on permeability & if concrete becomes saturated it is more liable to frost - action.
3. In some structural members permeability itself is of importance, such as, dams, water retaining tanks.

4.7 DURABILTY OF CONCRETE

- The durability of concrete is one of its most important properties because it is essential that concrete should be capable of withstanding the conditions for which it has been designed throughout the life of a structure.
- The durability of cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration.
- Durable concrete will retain its original form, quality, and serviceability when exposed to its environment.

Factors affecting Durability

Lack of durability can be caused by external agents arising from the environment or by internal agents within the concrete.

Causes can be categorized as

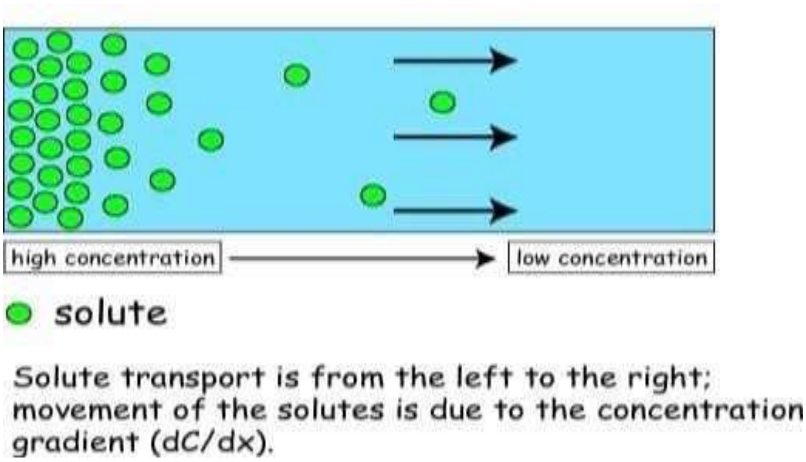
- Physical,
- Mechanical
- Chemical.

Physical causes

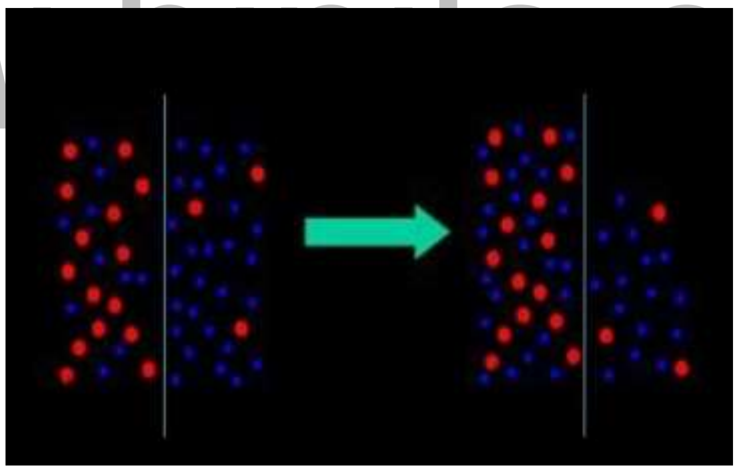
Physical causes arise from the action of frost and from differences between the thermal properties of aggregate and of the cement paste mechanical causes are associated mainly with abrasion.

Chemical causes

- Attack by sulfates, acids, sea water, and also by chlorides, which induce electrochemical corrosion of steel reinforcement.
- Since this attack takes place within the concrete mass, the attacking agent must be able to penetrate throughout the concrete, which therefore has to be permeable.



- Permeability is, therefore, of critical interest.
- The attack is aided by the internal transport of agents by diffusion due to internal gradients of moisture and temperature and by osmosis.



4.6 MODULUS OF ELASTICITY

Modulus of elasticity of concrete can be defined as the slope of the line drawn from a 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. One can easily obtain an approximate value of modulus of elasticity of concrete using 28 days concrete strength (f'_c) with its formulas. These formulas are based on the relationship between modulus of elasticity and concrete compressive strength.

Testing procedure

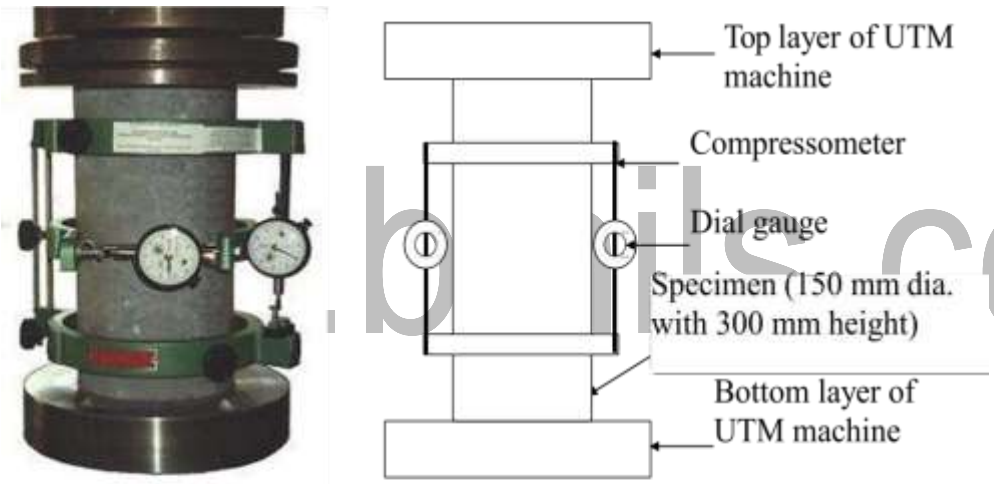
- Assemble the top and bottom frame by adjusting the screws.
- Keep the pivot rod on the screws and lock them in position.
- Keep the compressometer centrally on the specimen so that the tightening screw of the bottom and top frame are at equal distance from the two ends.
- Place the specimen with compressometer in the compression testing machine and center it.
- Apply load continuously without shock at a rate of 140 kg /cm^2/minute
- Maintain the load at this stress for at least one minute and reduce gradually to an average stress of 1.5 kg/ cm^2(a load of 0.3 Ton)
- Note the compressometer reading at this load.
- Reduce the load gradually and take readings at an interval of 1Ton
- Plot the graph using stress (y-axis) and strain (x-axis)
- Then the Young's modulus (Initial / Secant / Tangent) may be calculated by corresponding stress to strain.

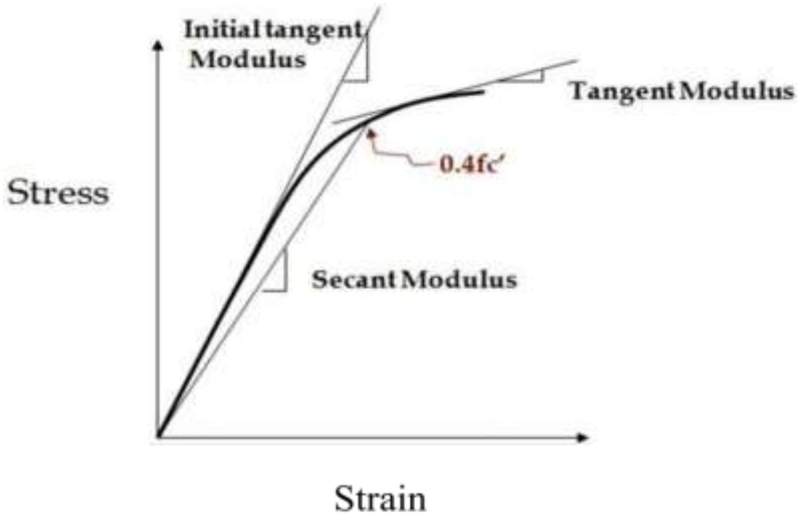
Graph

A graph is plotted between load and deflection, for loading and unloading conditions. The tangents at the initial portion of the loading curve and at the load corresponding to the working stress of the mix, is drawn. The initial point and the point on the loading curve corresponding to working stress are joined.

Calculation

Modulus of Elasticity = Stress/Strain (Load and deflection from the line joining initial point and the point at working stresses is considered)





4.8 PROPERTIES OF DURABILITY

4.8.1 WATER ABSORPTION

- The water absorption is determined by measuring the decrease in mass of a saturated and surface-dry sample after oven drying for 24 hours.
- The ratio of the decrease in mass to the mass of the dry sample, expressed as a percentage, is termed absorption.
- The assumption that oven-dry aggregate in an actual mix would absorb sufficient water to bring it to the saturated and surface-dry state may not be valid.
- The amount of water absorbed depends on the order of feeding the ingredients into the mixer and on the coating of coarse aggregate with cement paste.
- Therefore, a more realistic time for the determination of water absorption is 10 to 30 min rather than 24 hours.
- Moreover, if the aggregate is in an air-dry state, the actual water absorption will be correspondingly less.
- The actual water absorption of the aggregate has to be deducted from the total water requirement of the mix to obtain the effective water/cement ratio, which controls both the workability and the strength of concrete.

4.8.1.1 Understanding Water Transport Mechanisms in Concrete

- Moisture migration into concrete is the leading cause of concrete degradation.
- There are two primary water transport mechanisms in concrete.
- Considering water's powerful forces and then designing concrete structures to adequately resist the known effects of these two common water transport mechanisms is paramount to achieving durable structures.

- Designers, contractors, and owners need to thoroughly understand the differences in the mechanisms to ensure the structures they are building provide adequate problem-free service life.
- The two mechanisms listed by the magnitude of the challenge they impose are:

1. Capillary absorption

- Permeability
- Ignoring, or more commonly misunderstanding, this of the mechanisms provides the greatest threat to concrete leads to structures that fail to perform long-term and eventually will lead to structural failure.
- Most degradation processes encountered by concrete require water, dissolved chemicals, and the presence of oxygen.
- Dissolved salts (chlorides) or other deleterious chemicals can be rapidly transported to the steel reinforcement imbedded in the concrete through the capillary network.
- The resulting initiation of corrosion causes rebar to expand, breaking up the concrete it is embedded in.
- Additionally, in cases where water has permeated through a concrete substrate, it may damage building interiors. In each case, the presence of water is detrimental.

Rapid Deleterious Chemical Absorption through Capillaries

- As mix water required for concrete placement leaves concrete, it leaves behind a ***Porous capillary structure***.
- Capillary absorption is the primary transport mechanism for water in concrete structures.

- Capillary absorption is so powerful and rapid that it requires no pressure to function and creates far more damage potential than any of the other transport mechanisms.
- "The speed of capillary absorption is on the order of 10-6 m/s – a million times faster than pressure permeability."
- "***Capillary absorption*** is the primary transport mechanism by which water and chlorides infiltrate concrete" and that "clearly permeability is not a good indicator of resistance to chloride penetration".
- In often repeated studies and experiments, even extremely dense concrete mixes with high compressive strengths, low water cement ratios, and excellent pressure permeability readings rapidly transport water through capillary absorption.
- To ensure durable concrete it is absolutely essential to adequately address capillary absorption as the designer's primary duty.
- Permeability is the movement of water due to a pressure gradient, such as when concrete is under hydrostatic pressure.
- Performance under hydrostatic pressure is a simple function of concrete density, or cementitious content.
- Concrete's naturally dense matrix, (of even moderate quality mixes) provides an extremely difficult environment to push water through even under high pressure.
- The water pressure gradient encountered by a concrete structure is rapidly diminished by the resistance created by its relatively dense matrix.
- Concrete neutralizes the pressure gradient within the concrete very quickly and then capillary action once again becomes the primary transport mechanism and moves the water further into the structure.
- Fortunately, this transport mechanism is the least threatening, and is inexpensive to mitigate.

- Most designers overcome this challenge economically by simply increasing cementitious content (Portland cement, fly ash, slag, silica fume) or reducing the water/cement ratio to make it more difficult for water to be forced through concrete.
- Relatively small amounts of cementitious material may be added (for a small additional cost) to dramatically enhance concrete permeability performance.
- Although ***Diffusion*** is not a primary water transport mechanism it an excellent indicator of how deleterious materials can move through concrete structures.
- Chlorides can penetrate concrete by diffusion, which is the movement of chlorides in solution from an area of high concentration of chlorides to an area of lower concentration.
- Chlorides facilitate corrosion of steel reinforcement, which ultimately degrades concrete.
- Water has long been associated with deterioration processes affecting masonry materials.
- Its presence within the interior pore structure of masonry can result in physical destruction if the material undergoes wet/dry or freeze/thaw cycling.
- The latter is particularly damaging if the masonry material has high clay mineral content. Perhaps of greater importance is the fact that the presence of moisture is a necessary precondition for most deterioration processes.

4.8.2 PERMEABILITY

- Permeability is the ease with which liquids or gases can travel through concrete
- This property is of interest in relation to the water-tightness of liquid- retaining structures and to chemical attack

- Although there are no prescribed tests by ASTM and BS, the permeability of concrete can be measured by means of a simple laboratory test but the results are mainly comparative.
- In such a test, the sides of a concrete specimen are sealed and water under pressure is applied to the top surface only.
- When steady state conditions have been reached (and this may take about 10 days) the quantity of water flowing through a given thickness of concrete in a given time is measured.
- The water permeability is expressed as a *coefficient of permeability, k, given by Darcy's equation*
- The water permeability is expressed as a *coefficient of permeability, k, given by Darcy's equation*

$$\frac{1}{A}\frac{dq}{dt} = k\frac{\Delta h}{L}$$

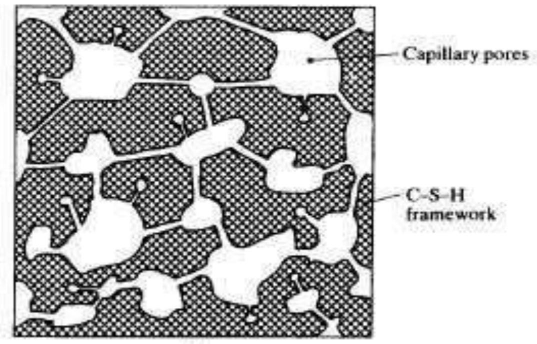
- where — is the rate of flow of water, *dt*
- *A is the cross-sectional area of the sample,*
- *Ah is the drop in hydraulic head through the sample, and*
- *L is the thickness of the sample.*
- The coefficient *k is expressed in m/sec or ft/sec.*

OTHER TESTS

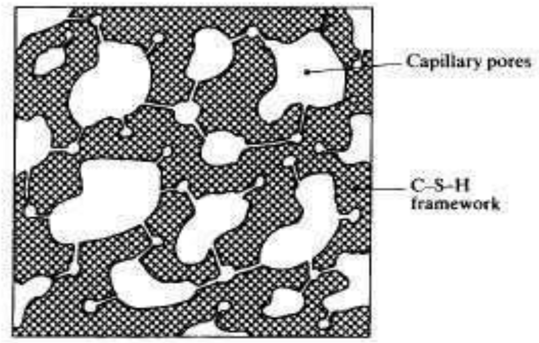
- ***INITIAL SURFACE ABSORPTION*** (BS 1881-5: 1970)
- Rate of flow of water into concrete per unit area, after a given time, under a constant applied load, and at a given temperature. This test gives information about the very thin 'skin' of the concrete only.

- Permeability of concrete to air or other gases is of interest in structures such as sewage tanks and gas purifiers, and in pressure vessels in nuclear reactors. Equation is applicable, but in the case of air permeability the steady condition is reached in a matter of hours as opposed to days.
- We should note, however, that there is no unique relation between air and water permeabilities for any concrete, although they are both mainly dependent on the water/cement ratio and the age of the concrete.
- For concrete made with the usual normal weight aggregate, permeability is governed by the porosity of the cement paste but the relation is not simple as the pore-size distribution is a factor.
- For example, although the porosity of the cement gel is 28 per cent, its permeability is very low, viz. 7×10^{-16} m/sec), because of the extremely fine texture of the gel and the very small size of the gel pores.
- The permeability of hydrated cement paste as a whole is greater because of the presence of larger capillary pores, and, in fact, its permeability is generally a function of capillary porosity.
- Since capillary porosity is governed by the water/cement ratio and by the degree of hydration, the permeability of cement paste is also mainly dependent on those parameters.
- For a given degree of hydration, permeability is lower for pastes with lower water/cement ratios, especially below a water/cement ratio of about 0.6, at which the capillaries become segmented or discontinuous.
- For a given water/cement ratio, the permeability decreases as the cement continues to hydrate and fills some of the original water space, the reduction in permeability being faster the lower the water/cement ratio.
- The large influence of segmenting of capillaries on permeability illustrates the fact that permeability is not a simple function of porosity.

- It is possible for two porous bodies to have similar porosities but different permeabilities,
- In fact, only one large passage connecting capillary pores will result in a large permeability, while the porosity will remain virtually unchanged.
- From the durability viewpoint, it may be important to achieve low permeability as quickly as possible.
- Consequently, a mix with a low water/cement ratio is advantageous because the stage at which the capillaries become segmented is achieved after a shorter period of moist curing.



(a)



(b)

- For normal weight concrete intended to have a low permeability when exposed to any type of water, the water/cementitious material ratio should be less than 0.50
- A maximum permeability of 1.5 x 10"" m/sec (4.8 x 10"" ft/sec) is often recommended.

- So far we have considered the permeability of cement paste which has been moist cured.
- The permeability of concrete is generally of the same order when it is made with normal weight aggregates which have permeability similar to that of the cement paste, but the use of a more porous aggregate will increase the permeability of concrete.
- Interruption of moist curing by a period of drying will also cause an increase in permeability because of the creation of water passages by minute shrinkage cracks around aggregate particles, especially the large ones.
- Permeability of steam-cured concrete is generally higher than that of moist-cured concrete and, except for concrete subjected to a long curing temperature cycle, supplemental fog curing may be required to achieve an acceptably low permeability.
- While a low water/cement ratio is essential for the concrete to have a low permeability, it is not by itself sufficient.
- The concrete must be dense, and therefore a well-graded aggregate has to be used, which can have a low water/cement ratio but a high permeability through passages outside the cement paste, as in the case of porous pipes.

4.8.3 SULFATE ATTACK

- Concrete attacked by sulfates has a characteristic whitish appearance, damage usually starting at the edges and corners and followed by cracking and spalling of the concrete.
- The reason for this appearance is that the essence of sulfate attack is the formation of calcium sulfate (gypsum) and calcium sulfoaluminate (ettringite), both products occupying a greater volume than the compounds which they replace so that expansion and disruption of hardened concrete take place.

4.8.4 CHLORIDE PENETRATION

- Chloride attack is particularly important because it primarily causes corrosion of reinforcement.
- Statistics have indicated that over 40 per cent of failure of structures is due to corrosion of reinforcement.
- The protective passivity layer can be lost due to carbonation.
- This protective layer also can be lost due to the presence of chloride in the presence of water and oxygen.

Measurement of Depth of Carbonation

Pink colour indicates that $Ca(OH)_2$ is unaffected by carbonation. The uncoloured portion indicates that concrete is carbonated.

Table 9.14. Limits of Chloride Content of Concrete (IS 456 of 2000)

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

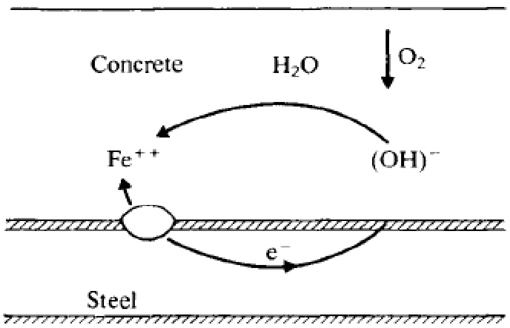
Limiting Chloride Content Corresponding to pH of concrete[9.20]

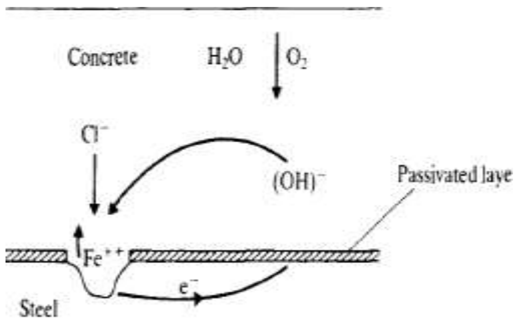
pH	Chloride content g/litre	ppm
13.5	6.7400	6740
13.0	2.1300	2130
12.5	0.6720	672
12.0	0.2130	213
11.5	0.0670	67
11.0	0.0213	21
10.0	0.0021	2
9.02	0.0002	0.2

Corrosion of Steel (Chloride induced)

- Chloride with water and oxygen leads to corrosion of reinforcement.
- The passive iron oxide layer is destroyed when the pH falls below about 11.0 and carbonation lowers the pH to about 9.
- The formation of rust results in an increase in volume compared with the original steel so that swelling pressures will cause cracking and spalling of the concrete.
- Corrosion of steel occurs because of electrochemical action which is usually encountered when two dissimilar metals are in electrical contact in the presence of moisture and oxygen.
- However, the same process takes place in steel alone because of differences in the electro-chemical potential on the surface which forms anodic and cathodic regions, connected by the electrolyte in the form of the salt solution in the hydrated cement.
- The positively charged ferrous ions Fe^{++} at the anode pass into solution

$$Fe \rightarrow Fe^{++} + 2e^- \text{ (anodic reaction)}$$
$$4e^- + O_2 + 2H_2O \rightarrow 4(OH)^- \text{ (cathodic reaction)}$$
$$Fe^{++} + 2(OH)^- \rightarrow Fe(OH)_2 \text{ (ferrous hydroxide)}$$
$$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3 \text{ (ferric hydroxide).}$$





- Chloride ions present in the cement paste surrounding the reinforcement react at anodic sites to form hydrochloric acid which destroys the passive protective film on the steel.
- The surface of the steel then becomes activated locally to form the anode, with the passive surface forming the cathode; the ensuing corrosion is in the form of localized pitting. In the presence of chlorides, the schematic reactions are a

$$Fe^{++} + 2Cl^{-} \rightarrow FeCl_2$$
$$FeCl_2 + 2H_2O \rightarrow Fe(OH)_2 + 2HCl$$

- Thus, Cl^- is regenerated. The other reactions, and especially the cathodic reaction, are as in the absence of chlorides.
- We should note that the rust contains no chloride, although ferric chloride is formed at an intermediate stage.
- Because of the acidic environment in the pit, once it has formed, the pit remains active and increases in depth. Pitting corrosion takes place at a certain potential, called the pitting potential.

4.8.5 CORROSION

4.8.5.1 Ways to Control Corrosion

- Metallurgical methods
- Corrosion inhibitors
- Coatings to reinforcement

- Cathodic protection
- Coatings to concrete
- Design and detailing

Metallurgical Methods:

- By altering its structure.
- rapid quenching of the hot bars by series of water jets, or by keeping the hot steel bars for a short time in a water bath, stainless steel reinforcements are used for long term durability of concrete structures.

Corrosion inhibitors:

- Nitrites, Phosphates, Benzoates
- The most widely used admixture is based on calcium nitrite.

Coatings to reinforcement:

- The coatings should be robust to withstand fabrication of reinforcement cage, and pouring of concrete and compaction by vibrating needle.
- Simple cement slurry coating

STEPS INVOLVED….

1. Derusting:

- Derusting solution.
- Cleaning the rods with wet waste cloth and cleaning powder.
- The rods are then rinsed in running water and air dried.

2. Phosphating:

- Phosphate jelly is applied to the bars with fine brush
- An inhibitor solution is then brushed over the phosphate surface.

3. Cement coating:
4. Sealing:
5. Fusion Bonded Epoxy Coating:
6. Galvanised reinforcement:
7. Cathodic Protection:

- Application of impressed current to an electrode laid on the concrete above steel reinforcement.
- This electrode serves as anode and the steel reinforcement which is connected to the negative terminal of a DC source acts as a cathode.
- In this process the external anode is subjected to corrode and the cathodic reinforcement is protected against corrosion and hence the name "Cathodic protection".

8. Coatings to Concrete:

- coated with Emcee color Flex,

9. Design and Detailing:
10. Nominal Cover to Reinforcement:

4.8.5.2 CORROSION TEST

The measurement of steel reinforcement corrosion in concrete is essential to analyze the strength and durability of structure.

Resistivity meter and Corrosion analyzing instrument which are easily available can measure these properties.

Resistivity meter for measuring corrosion

The corrosion of steel in concrete is an electrochemical reaction which generates a flow of current. Resistivity of the concrete influences the flow of this current. The lower the electric resistance, the more easily corrosion current flow through the concrete and the greater is the probability of corrosion. Thus the resistivity of concrete is a good indication of probability of corrosion.

4.8.6 ACID RESISTANCE

In general, cement concrete have low resistance to acids. It can withstand some weak acidic attacks; however, the overall acid resistance of the cement concrete is low. Following measures are used to improve concrete's resistance to acids.

1. By choosing the correct concrete composition, to make it as impermeable as possible.
2. Keeping the concrete surface, from the environment by using a suitable coating.
3. Modifying the environment to make it less aggressive to the concrete.
4. Siliceous aggregates are resistant to most acids and other chemicals and are sometimes specified to improve the chemical resistance of concrete.

4.2 SEGREGATION AND BLEEDING

Bleeding

The tendency of water to rise to the surface of freshly laid concrete is known as bleeding. Bleeding is generally occurred due to higher water cement ratio It is defined as some of the water is come out to the surface of the concrete.

Steps adopted to control bleeding

- By adding more cement
- By using more finely ground cement
- By using little air entraining agent
- By increasing finer part of fine aggregate
- By properly designing the mix and using minimum quantity of water.

Causes of Bleeding

- Improper mixing
- Improper mix design
- Highly wet mix
- Heavy compassion (or) vibration

Segregation

The tendency of separation of coarse aggregate grains from the concrete mass is called segregation. *Aggregates and cement paste are separated* due to higher water cement ratio or poor mix proportions It is also seriously affecting the quality of the concrete.

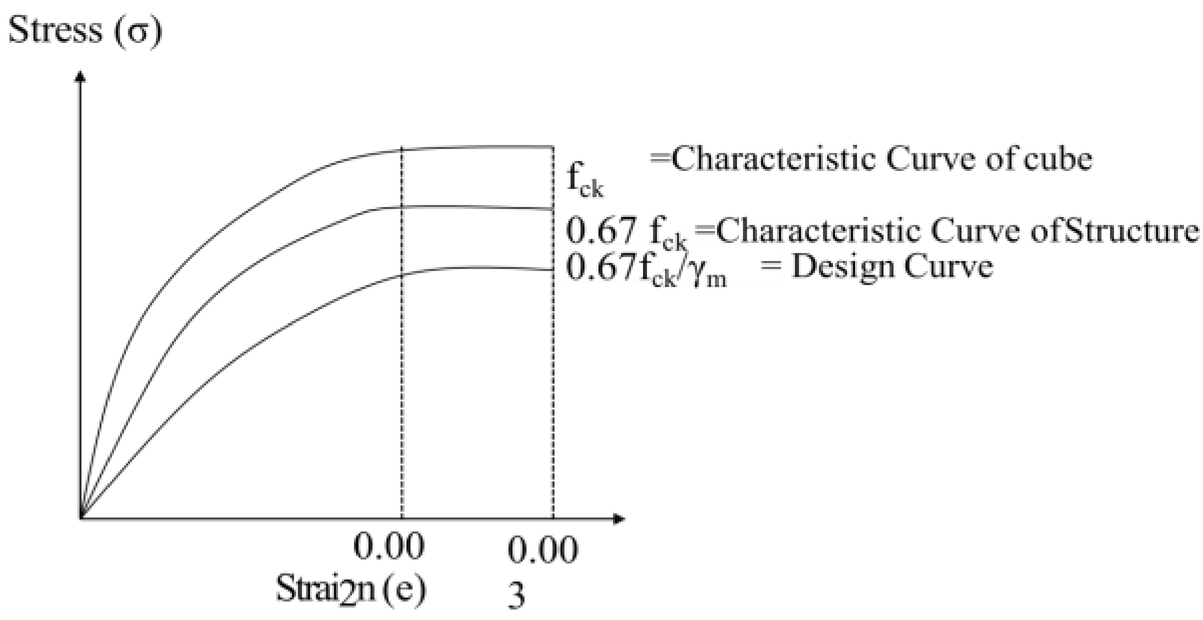
Causes of Segregation

- Improper mixing of concrete
- Improper mix design
- Dropping of concrete from heights
- Discharging concrete against obstacles
- Passing the concrete along the chute, when changing its direction
- Concrete discharge from a badly designed mixer or from a mixer of damaged blades
- During the conveyance of concrete, hauling
- Excessive vibration to high wet mix
- Improper finishing of concrete surface

Reduction of Segregation

- By using exact proportion (or) mix
- By using air – entraining agents
- Preventing the flow of concrete
- Reducing the continuous vibration for long time
- By using of workability agents
- Reducing the height of drop of concrete

4.5 STRESS-STRAIN CURVE FOR CONCRETE



- The Figure showing the stress – strain curve for concrete. Usually, the curve may be assumed to be rectangular, trapezoidal, parabola or any other shape.
- The curve will be linear in lower grade of concrete and nonlinear in higher grade of concrete.
- The reason for this nonlinear behavior is that micro cracks are formed,
  - i. At the interface between aggregate particles and cement paste as a result of the differential movement between the two phases, and
  - ii. Within the cement paste itself.
- These cracks are formed as a result of change in temperature and moisture and the application of load.
- Concrete taken through a cycle of loading and unloading will exhibit a stress-strain curve as shown in the figure.
- For design purposes, the compressive strength of concrete in the structure shall be assumed to be 0.67 times the characteristic strength.
- The partial safety factor γ_m, = 1.5 shall be applied in addition to this.

- While studying the stress-strain relationship, tensile strength of the concrete is ignored.
- The concrete will not return to its original length when unloading mainly due to creep and micro-crackling.
- There will be a residual strain at zero loads. This is known as hysteresis loop.
- Hysteresis loop is mainly related to micro-cracking.
- Providing the maximum applied load is not greater than the normal working load, and then further cycles of loading and unloading will produce small size hysteresis loops.
- This because the majority of the micro-cracks are formed on the first application of the load.

4.4 TEST ON HARDENED CONCRETE

Many destructive and non-destructive tests are conducted on hardened concrete to measure their properties such as strength, permeability and durability;

Destructive testing

(Specimen is broken down)

1. Compressive strength test
2. Flexural Strength test
3. Splitting tensile test
4. Modulus of elasticity
5. Pull out test etc.

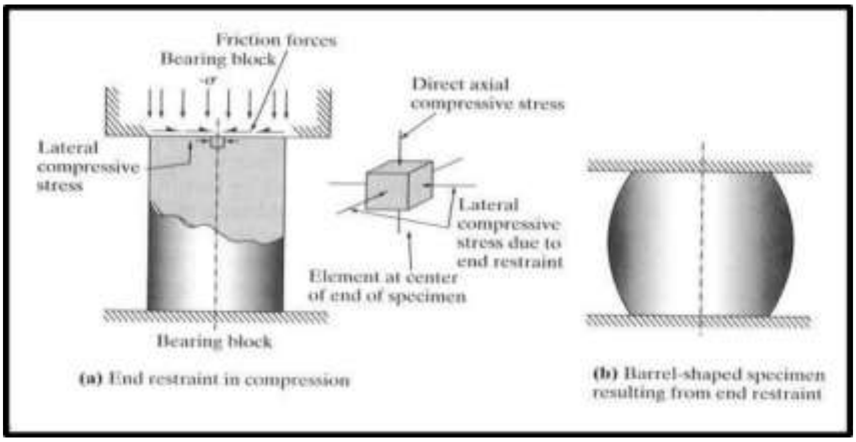
Non-Destructive testing

(Specimen is not broken down)

1. Ultrasonic pulse velocity test
2. Rebound hammer test
3. Electrical resistivity test
4. Other corrosion studies

4.4.1 COMPRESSIVE STRENGTH

The compressive strength of the 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 + 2°C for 28 days.

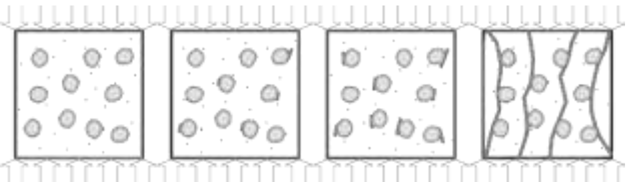


Testing procedure

- These cured specimens are taken from the curing tank and excess water is removed from the surface.
- The cleaned specimens are tested by compression testing machine after 7 days curing or 28 days curing as required.
- Load should be applied gradually till the Specimens fails.
- Load at the failure is noted and the compressive strength of concrete can be calculated by the *ratio of failure load to surface area of the specimen i.e. f= P/A*

As per Indian standard code, the compressive strength improvement percentages is presented in the table

Curing period in days	Strength improvement in percentage
1	16
3	40
7	65
14	90
28	99



(a) (b) (c) (d)

Failure process of a concrete under compression:

(a) shear-bond crack (load less than 40% ultimate value);

(b) load-initiated cracks (load between 40 and 80% ultimate value);

(c) Crack concentration (load greater than 80% ultimate value);

(d) Major cracks formed (failure indication)

4.4.2 TENSILE STRENGTH

Tensile strength is one of the basic and important properties of concrete. A knowledge of its value is required for the design of concrete structural elements. Its value is also used in the design of prestressed concrete structures, liquid retaining structures, roadways and runway slabs. Direct tensile strength of concrete is difficult to determine; recourse is often taken to the determination of flexural strength or the splitting tensile strength and computing the direct tensile.

4.4.2.1 SPLIT TENSILE STRENGTH TEST

A method of determining the tensile strength of concrete using a cylinder which splits across the vertical diameter. It is an indirect method of testing tensile strength of concrete.

- In direct tensile strength test it is impossible to apply true axial load. There will be always some eccentricity present.
- Another problem is that stresses induced due to grips. Due to grips there is a tendency for specimen to break at its ends.

Test Specimens

Cylinder

- The length of the specimens shall not be less than the diameter and not more than twice the diameter. For routine testing and comparison of results, unless otherwise specified the specimens shall be cylinder 150 mm in diameter and 300 mm long.

Curing

- The procedure of making and curing tension test specimen in respect of sampling of materials, preparation of materials, proportioning, weighing, mixing, workability, moulds, compacting and curing shall comply in all respects with the requirements given in IS 516.

Sampling of Materials

- Representative samples of the materials of concrete for use in the particular concrete construction work shall be obtained by careful sampling.
- Test samples of cement shall be made up of a small portion taken from each of a number of bags on the site. Test samples of aggregate shall be taken from larger lots.

Preparation of Materials

- All materials shall be brought to room temperature, preferably 27°±3°C before commencing the tests.
- The cement samples, on arrival at the laboratory, shall be thoroughly mixed dry either by hand or in a suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material, care being taken to avoid the intrusion of foreign matter. The cement shall then be stored in a dry place, preferably in air-tight metal containers.
- Samples of aggregates for each batch of concrete shall be of the desired grading and shall be in an air-dried condition. In general, the aggregate shall be separated into fine and coarse fractions and recombined for each concrete batch in such a manner as to produce the desired grading.

Weighing

- The quantities of cement, each size of aggregate, and water for each batch shall be determined by weight, to an accuracy of 0.1 percent of the total weight of the batch.

Mixing Concrete

- The concrete shall be mixed by hand, or preferably, in a laboratory batch mixer, in such a manner as to avoid loss of water or other materials. Each batch of concrete shall be of such a size as to leave about 10 percent excess after moulding the desired number of test specimens.

Moulds

Cylinders

- The cylindrical mould shall be of 150mm diameter and 300mm height. Similarly the mould and base plate shall be coated with a thin film of mould oil before use, in order to prevent adhesion of the concrete.

Test for Split Tensile Strength

Aim:

To determine the splitting tensile strength for the concrete specimen.

Apparatus:

1. Weights and weighing device.
2. Tools, containers and pans for carrying materials & mixing.
3. A circular cross-sectional rod (φl6mm & 600mm length).
4. Testing machine.
5. Three cylinders (φ150mm & 300mm in height).
6. A jig for aligning concrete cylinder.

The jig for aligning concrete cylinder and bearing strips

Procedure:

1. Prepare three cylindrical concrete specimens.

2. After moulding and curing the specimens for seven days in water, they can be tested. The cylindrical specimen is placed in a manner that the longitudinal axis is perpendicular to the load.
3. Two strips of nominal thick plywood, free of imperfections, approximately (25mm) wide, and of length equal to or slightly longer than that of the specimen should be provided for each specimen.
4. The bearing strips are placed between the specimen and both upper and lower bearing blocks of the testing machine.
5. The load shall be applied without shock and increased continuously at a nominal rate within the range 1.2 N/ (mm2/min) to 2.4 N/ (mm2/min).
6. Record the maximum applied load indicated by the testing machine at failure. Note the type of failure and appearance of fracture.

Computations: Calculate the splitting tensile strength of the specimen as follows:

$$T = \frac{2P}{\pi L d}$$

Where:

T: splitting tensile strength, kPa

P: maximum applied load indicated by testing machine, kN

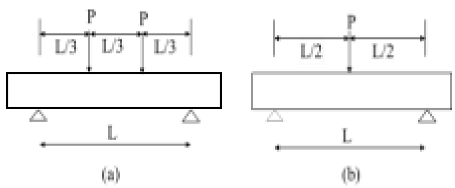
L: Length, m

d: diameter, m

Result

- It is found that the splitting test is closer to the true tensile strength of concrete it gives about 5 to 12% higher value than the direct tensile strength test.

4.4.2.2 FLEXURAL TENSILE STRENGTH TEST



Test procedure:

- Prepare the test specimen by filling the concrete into the mould in 3 layers of approximately equal thickness. Tamp each layer 25 times using the tamping bar.
- The specimen is placed to the machine as shown in above figure.
- Hence the load is applied gradually to the specimen and failure of the specimen is carefully noted.
- After getting of failure loading, the flexural strength can be calculated by using following expression,

$$fb = PL/bd^2$$

Where, P-load, L-Length of the specimen, B and d- breadth and depth of specimen

UNIT- IV

FRESH AND HARDENED PROPERTIES OF CONCRETE

SYLLABUS

Workability - Tests for workability of concrete - Segregation and Bleeding - Determination of strength Properties of Hardened concrete - Compressive strength – split tensile strength - Flexural strength - Stress-strain curve for concrete - Modulus of elasticity – durability of concrete – water absorption – permeability – corrosion test – acid resistance.

4.1 WORKABILITY

- 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.
- Workability is one of the physical parameters of concrete which affects the strength and durability as well as the cost of labor and appearance of the finished concrete. Concrete is said to be workable when it is easily placed and compacted homogeneously i.e. *without bleeding or Segregation.*

Requirements of fresh concrete

- Mixability
- Stability
- Mobility

- Compactability
- Finishability

Factor affecting the workability:

a) Water content

b) Mix proportion

c) Size of aggregate

d) Shape of aggregate

e) Surface texture of aggregate

f) Grading of admixture

g) Use of admixtures (Chemical / mineral admixtures)

Water content or Water Cement Ratio

▶ More the water cement ratio ,more workability of concrete. Since by simply adding water the inter particle lubrication is increased.

▶ High water content results in a higher fluidity and greater workability. Increased water content also results in bleeding. another effect of increased water content can also be that cement slurry will escape through joints of formwork.

▶ More water can be added, provided a correspondingly higher quantity of cement is also added to keep the water/cement ratio constant, so that the strength remains the same.

Mix proportion

▶ The higher the aggregate / cement less quantity of paste is available for providing lubrication, per unit surface area of aggregate and hence the mobility of aggregate is restrained.

▶ On the other hand, in case of rich concrete with lower aggregate/cement ratio, more paste is available to make the mix cohesive and fatty to give better workability.

Size of Aggregate & Surface Texture

▶ The bigger the size of the aggregate, the less is the surface area and hence less amount of water is required for wetting the surface and less matrix or paste is required for lubricating the surface to reduce internal friction.

▶ Greater size of Aggregate- less water is required to lubricate it, the extra water is available for workability

▶ Porous aggregates require more water compared to non-absorbent aggregates for achieving same degree of workability.

Shape of aggregate

▶ Angular, elongated or flaky aggregate makes the concrete very harsh when compared to rounded aggregates or cubical shaped aggregates.

▶ Contribution to better workability of rounded aggregate will come from the fact that for the given volume or weight it will have less surface area and less voids than angular or flaky aggregate.

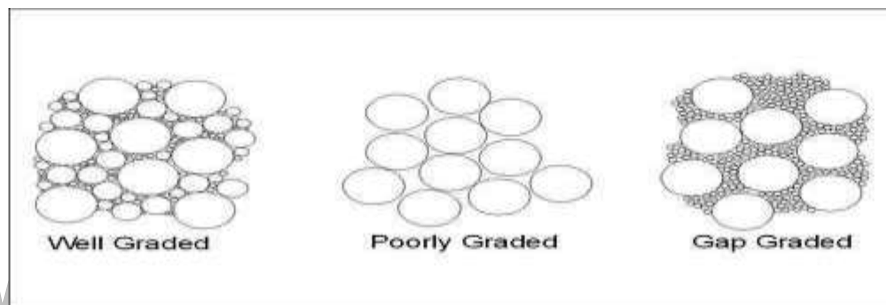
▶ Not only that, being round in shape, the frictional resistance is also greatly reduced. This explains the reason why river sand and gravel provide greater workability to concrete than crushed sand and aggregate.

Grading of admixture

▶ A well graded aggregate is the one which has least amount of voids in a given volume and higher the workability.

▶ Other factors being constant, when the total voids are less, excess paste is available to give better lubricating effect.

▶ With excess amount of paste, the mixture becomes cohesive and fatty which prevents segregation of particles.



Use of admixtures

▶ Chemical admixtures can be used to increase workability.

▶ Use of air entraining agent produces air bubbles which acts as a sort of ball bearing between particles and increases mobility, workability and decreases bleeding, segregation.

▶ The use of fine pozzolanic materials also have better lubricating effect and more workability.

Weather Conditions

▶ If temperature is high, evaporation increases, thus workability decreases.

▶ If wind is moving with greater velocity, the rate of evaporation also increase reduces the amount of water and ultimately reducing workability.

4.1.1 TESTS FOR WORKABILITY OF CONCRETE

a. Slump Test

b. Compaction Factor

c. Vee - Bee Consistometer

d. Kelly Ball Penetration test

e. Flow table Test

f. Vibrating table

4.1.1.1 Slump Test

Definition

A slump test is a method used to determine the consistency of concrete. The consistency, or stiffness, indicates how much water has been used in the mix. The stiffness of the concrete mix should be matched to the requirements for the finished product quality

- Slump is a measurement of concrete's workability, or fluidity.
- It's an indirect measurement of concrete consistency or stiffness.

Principle

The slump test result is a measure of the behaviour of a compacted inverted cone of concrete under the action of gravity. It measures the consistency or the wetness of concrete.

Apparatus

- Slump cone : inverted cone, 300 mm (12 in) of height. The base is 200 mm (8in) in diameter and it has a smaller opening at the top of 100 mm
- Scale for measurement,
- Temping rod(steel) 16mm diameter, 60cm length.

Procedure

- The base is placed on a smooth surface and the container is filled with concrete in three layers, whose workability is to be tested.
- Each layer is temped 25 times with a standard 16 mm (5/8 in) diameter steel rod, rounded at the end.
- After the top layer has been tamped, the concrete is struck off level with trowel and tamping rod.
- Then, the mould is removed by lifting it slowly and carefully in a vertical direction.
- This allows the concrete to subside. This subsidence is referred as slump concrete.
- The difference in level between the height of the mould and that of the highest point of the subsided concrete is measured. This difference in height in mm is taken as slump of concrete.

a. True slump:

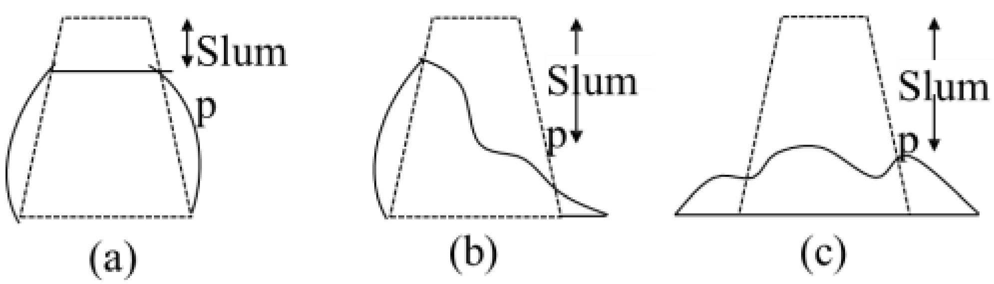
In this type of slump, the concrete is settled less from the top, and there is no any segregation on its shapes and indicate low workability

b. Shear slump:

In a shear slump, the top portion of the concrete shears off and slips sideways This kind of shear slip of concrete is clearly indicating the lack of cohesion of the concrete mix.

c.* Collapse slump*:

In this type of slump, the concrete is completely collapsed due to higher water cement ratio of the mix. This collapse indicates that the higher fluidity of the mix and instability of the mix, which cannot be used in any kind of important structures.



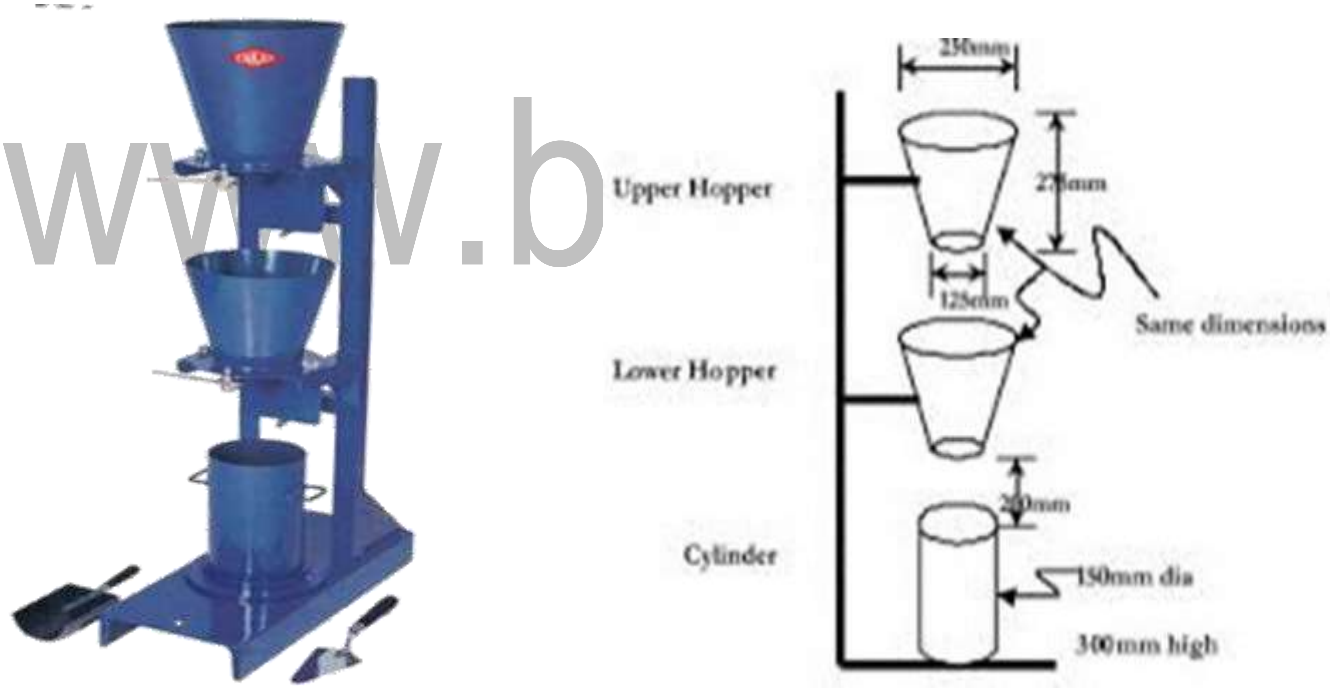
(a) True Slump *(b) Shear Slump* *(c) Collapse Slump*

4.1.1.2 Compacting factor test

Introduction

- Compacting factor test, developed at the road research laboratory UK is more precise and sensitive than the slump test. It is primarily designed for laboratory work but can also be used in the field. It is particularly useful for concrete mixes of very low workability as are normally used when concrete is to be compacted by vibration such concrete may constantly fail to slump.

For the normal range of concrete the compacting factor lies between 0.8-0.92



Compaction factor test apparatus

Apparatus

- Trowels
- Hand Scoop (15.2 cm long)
- Rod of steel or other suitable material (1.6 cm diameter, 61 cm long rounded at one end).
- Balance.

Procedure

1) Ensure the apparatus and associated equipment are clean before test and free from hardened concrete and superfluous water .
2) Weigh the bottom cylinder to nearest 10gm , put it back on the stand and cover it up with a pair of floats .
3) Gently fill the upper hopper with the sampled concrete to the level of the rim with use of a scoop .
4) Immediately open the trap door of the upper hopper and allow the sampled concrete to fall into the middle hopper .
5) Remove the floats on top of the bottom cylinder and open the trap door of the middle hopper allowing the sampled concrete to fall into the bottom cylinder .

6) Remove the surplus concrete above the top of the bottom cylinder by holding a float in each hand and move towards each other to cut off the concrete across the top of cylinder.

7) Wipe clean the outside of cylinder of concrete and weigh to nearest 10gm .

8) Subtract the weight of empty cylinder from the weight of cylinder plus

Concrete to obtain the weight of partially compacted concrete .

9) Remove the concrete from the cylinder and refill with sampled concrete in layers .

10) Compact each layer thoroughly with the standard Compacting Bar to achieve full compaction .

11) Float off the surplus concrete to top of cylinder and wipe it clean .

12) Weigh the cylinder to nearest 10gm and subtract the weight of empty cylinder from the weight of cylinder plus concrete to obtain the weight of fully compacted concrete .

$$\text{The Compacting Factor } (CF) = \frac{\text{weight of partially compacted concrete}}{\text{weight of fully compacted concrete}}$$

Workability	Slump (mm)	C.F	Uses
Very Low	0 - 25	0.78	Roads - Pavements
Low	25 - 50	0.85	Foundations Concrete
Medium	25 - 100	0.92	Reinforced Concrete
High	100 - 175	0.95	Reinforced Concrete (High Reinforcement)

4.1.1.3 Flow Test

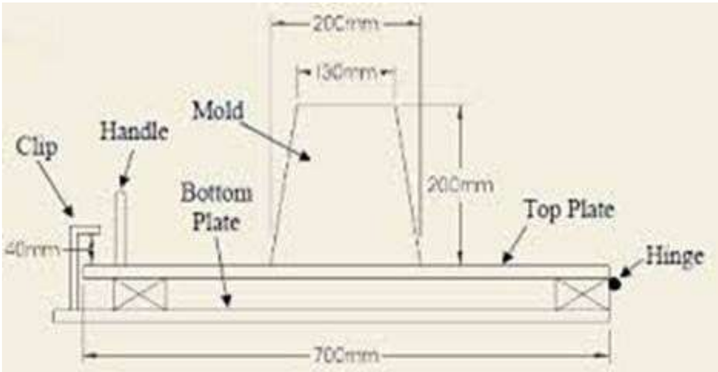
Definition

The **flow table test** or **flow test** is a method to determine the consistency of fresh concrete.

- Application When fresh concrete is delivered to a site by a truck mixer it is sometimes necessary to check its consistence before pouring it into formwork.
- If the consistence is not correct, the concrete will not have the desired qualities once it has set, particularly the desired strength. If the concrete is too pasty, it may result in cavities within the concrete which leads to corrosion of the rebar, eventually leading to the formation of cracks (as the rebar expands as it corrodes) which will accelerate the whole process, rather like insufficient concrete cover. Cavities will also lower the stress the concrete is able to support.

Equipment

- Flow table with a grip and a hinge, 70 cm x 70 cm.
- Abrams cone, open at the top and at the bottom - 30 cm high, 17 cm top diameter, 25 cm base diameter
- Water bucket and broom for wetting the flow table.
- Tamping rod, 60 cm height
- Scale for measurement



Flow Table Test Apparatus

Procedure:

- The flow table is wetted
- The cone is placed on the flow table and filled with fresh concrete in two layers, each layer 25 times tamp with tamping rod.
- The cone is lifted, allowing the concrete to flow.
- The flow table is then lifted up several centimeters and then dropped, causing the concrete flow a little bit further.
- After this the diameter of the concrete is measured in a 6 different direction and take the average.

Flow table apparatus

$$Flow\ \% = \frac{Diameter\ of\ flow\ (cm) - 25}{25} \times 100$$

	0 – 20 ⁰/J		60-root	I00 – J20 ⁰/J	120 – ISO ⁰/ñ
Consistent	Dy	$tlJ	Plastic	Set	Sloppy