Cement

A **cement** is a binder, a substance used in construction that sets and hardens and can bind other materials together. The most important types of cement are used as a component in the production of mortar in masonry, and of concrete, which is a combination of cement and an aggregate to form a strong building material.

Cements used in construction are usually inorganic, often lime based, and can be characterized as being either **hydraulic** or **non-hydraulic**, depending upon the ability of the cement to set in the presence of water (see hydraulic and non-hydraulic lime plaster).

Cement

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 is resistant to attack by chemicals after setting.

Hydraulic cements (e.g., Portland cement) set and become adhesive due to a chemical reaction between the dry ingredients and water. The chemical reaction results in mineral 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.

Ingredients

Cement is manufactured by crushing, milling and proportioning the following materials:

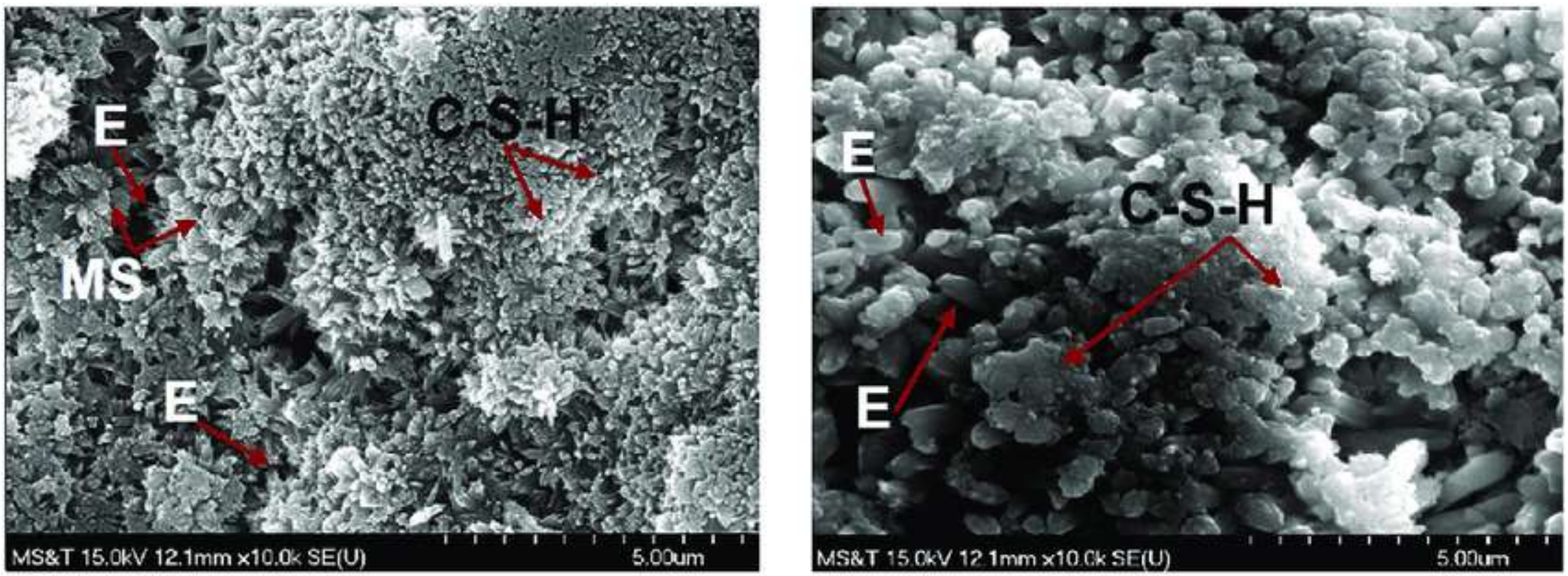
- Lime or calcium oxide, CaO: from limestone, chalk, shells, shale or calcareous rock
- Silica, SiO_2: from sand, old bottles, clay or argillaceous rock
- Alumina, Al_2O_3: from bauxite, recycled aluminum, clay
- Iron, Fe_2O_3: from clay, iron ore, scrap iron and fly ash
- Gypsum, $CaSO_4.2H_20$: found together with limestone

Composition of Cement

There are eight major ingredients of cement.

Lime	-	60-65
Silica	-	17-25
Alumina	-	3-8
Magnesia	-	1-3
Iron oxide	-	0.5-6
Calcium Sulfate	-	0.1- 0.5
Sulfur Trioxide	-	1-3
Alkaline	-	0-1

Z-Cem 1


E
C-S-H
MS
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MS&T 15.0kV 12.1mm x10.0k SE(U)
5.00um
E
C-S-H
E
MS&T 15.0kV 12.1mm x10.0k SE(U)
5.00um

(a) (b)

Composition of Cement

- **Lime**: Lime is calcium oxide or calcium hydroxide.
  - Presence of lime in a sufficient quantity is required to form silicates and aluminates of calcium.
  - Deficiency in lime reduces the strength of property to the cement.
  - Deficiency in lime causes cement to set quickly.
  - Excess lime makes cement unsound.
  - Excessive presence of lime cause cement to expand and disintegrate.

- **Silica**: Silicon dioxide is known as silica, chemical formula SiO_2.
  - Sufficient quantity of silica should be present in cement to dicalcium and tricalcium silicate.
  - Silica imparts strength to cement.
  - Silica usually present to the extent of about 30 percent cement.

Composition of Cement

- **Alumina**: Alumina is Aluminium oxide. The chemical formula is Al_2O_3.
  - Alumina imparts quick setting property to the cement.
  - Clinkering temperature is lowered by the presence of the requisite quantity of alumina.
  - Excess alumina weakens the cement.

- **Magnesia**: Magnesium Oxide. Chemical formula is MgO.
  - Magnesia should not be present more than 2% in cement.
  - Excess magnesia will reduce the strength of the cement.

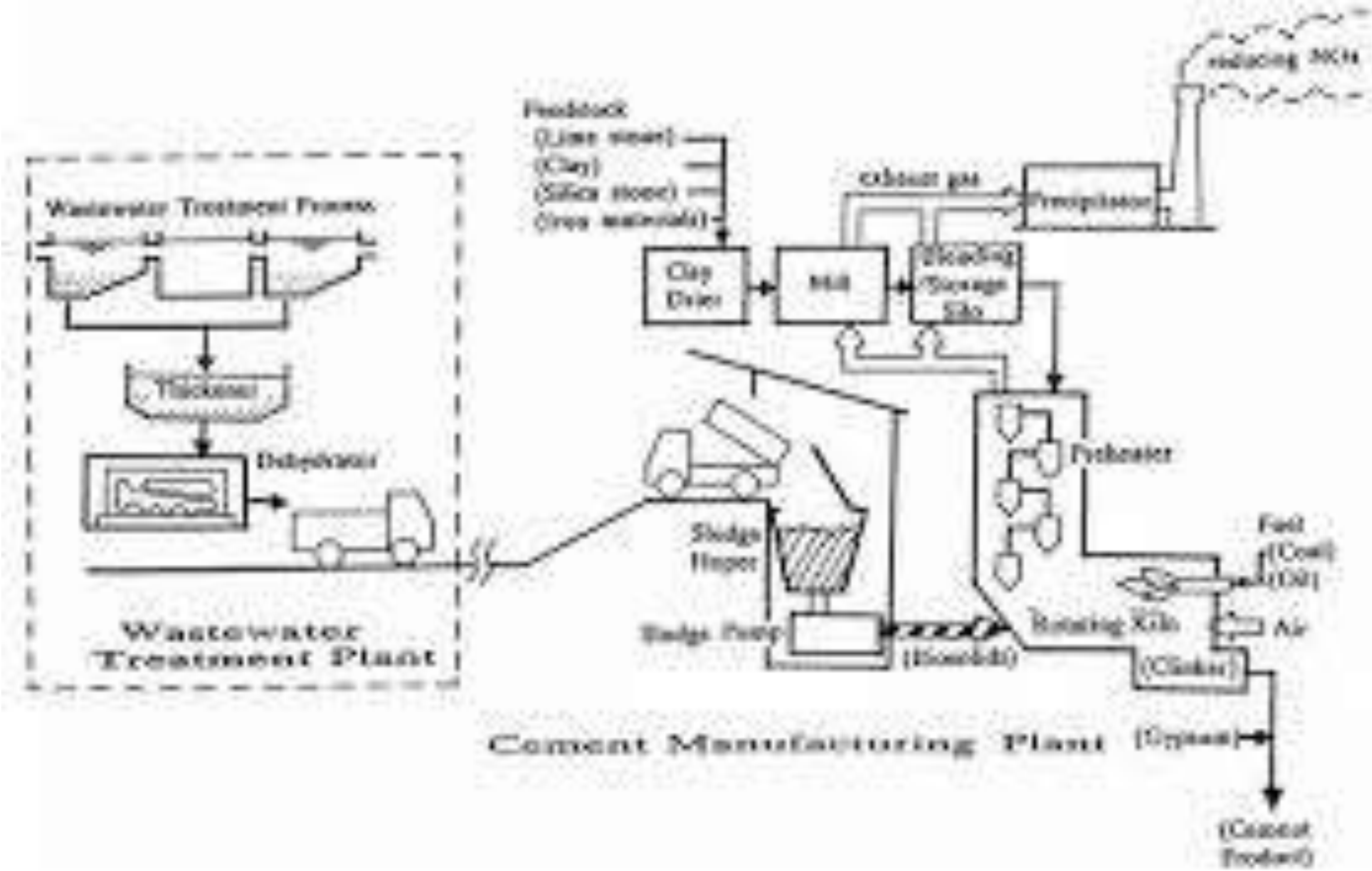
- **Iron oxide**: Chemical formula is Fe_2O_3.
  - Iron oxide imparts color to cement.
  - It acts as a flux.
  - At a very high temperature, it imparts into the chemical reaction with calcium and aluminum to form tricalcium alumino-ferrite.
  - Tricalcium alumino-ferrite imparts hardness and strength to cement.

Composition of Cement

- **Calcium Sulfate**: Chemical formula is $CaSO_4$
  - This is present in cement in the form of gypsum($CaSO_4.2H_2O$)
  - It slows down or retards the setting action of cement.
- **Sulfur Trioxide**: Chemical formula is SO_3
  - Should not be present more than 2%.
  - Excess Sulfur Trioxide causes cement to unsound.
- **Alkaline**:
  - Should not be present more than 1%.
  - Excess Alkaline matter causes efflorescence.

Manufacturing - WET PROCESS

1) Collection of raw materials – Limestone, clay
2) Crushing, grinding & mixing of raw materials
   - Limestone finely grained in ball mill & dispersed in water in wash mill
   - Clay mixed with water in separate wash mill
   - These 2 mixtures are well mixed (predetermined concentration) to form slurry
   - slurry (35 – 40 % of water) is stored in storage tanks
   - From storage tanks slurry is passed into Silos (here proportioning is finely adjusted)



Feedstock
(Clay)
(Silica stone)
exhaust gas
Precipitator
Clay Drier
Mill
Preheater
Wastewater Treatment Process
Thickener
Dehydrator
Sludge Hopper
Sludge Pump
Rotating Kiln
Fuel
(Coal)
(Oil)
Air
(Clinker)
Wastewater Treatment Plant
Cement Manufacturing Plant
(Gypsum)

WET PROCESS

3) Burning

- From silos slurry is pumped to upper end of rotary kiln
- Rotary kiln : length – 150 m, Rotated in horizontal axis
- By rotating slurry moved towards lower end - temp reaches about 1500^{o}C @ lower end
- When slurry moves from one end to other, a series of chemical reaction occur
- At hottest part of kiln, lime, alumina & silica recombine and forms Clinker (0.3 cm to 2.5 cm dia)

4) Grinding

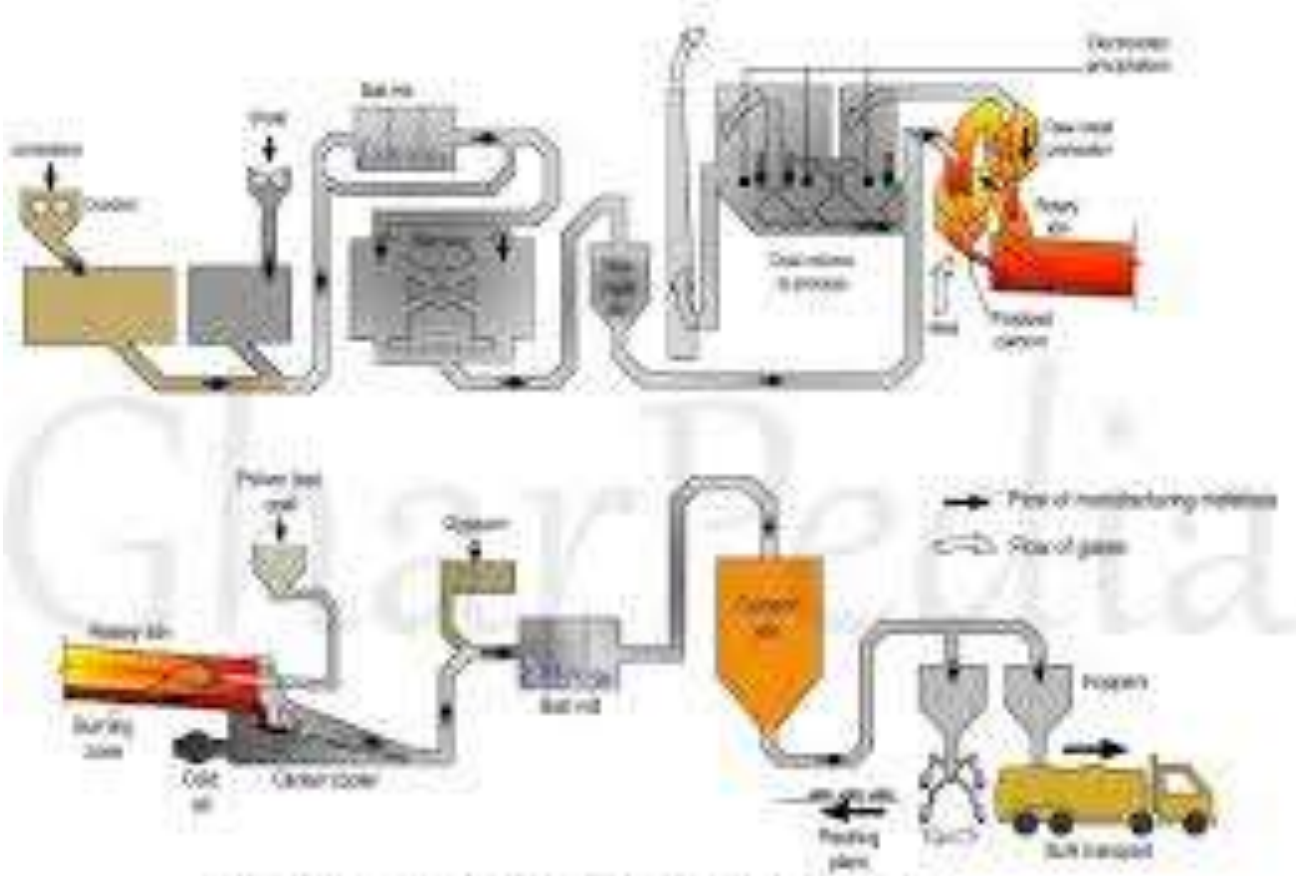
- 3 to 4 % gypsum is added to prevent flash setting
- Grinding is done in ball mills containing smaller steel balls

DRY PROCESS

- Materials are crushed & fed in correct proportion into grinding mill
- In grinding mill, materials are dried and reduced in size to fine powder
- Fine powder is also called raw meal
- Raw meal is pumped into blending silo and final adjustment is made in proportion
- Blending in silo is achieved by compressed air
- Blended meal is sieved and fed into Granulator. Also 12% of water is added.
- After adding water, Hard pallets of 1.25 cm dia are formed
- Pallets are baked in pre-heating grate by means of hot gases.
- Then pre heated pallets are introduced into kiln

  (Rest all procedure are same as wet procedure)
- Pallets contain only 12% moisture (40% in wet process)
- So amount of heat required is greatly reduced

DRY PROCESS



Dry Process for Manufacturing of Cement

Properties of cement compounds

These compounds contribute to the properties of cement in different ways

Tricalcium aluminate, C_3A:- It liberates a lot of heat during the early stages of hydration, but has little strength contribution. Gypsum slows down the hydration rate of C_3A . Cement low in C_3A is sulfate resistant.

Tricalcium silicate, C_3S:- This compound hydrates and hardens rapidly. It is largely responsible for portland cement's initial set and early strength gain.

Dicalcium silicate, C_2S: C_2S hydrates and hardens slowly. It is largely responsible for strength gain after one week.

Tetracalcium aluminoferrite, C_4AF: This is a fluxing agent which reduces the melting temperature of the raw materials in the kiln (from 3,000^o F to 2,600^o F). It hydrates rapidly, but does not contribute much to strength of the cement paste.

Cement General properties

- Unit weight = 1440 kg/m^3

Properties

- Provides strength to masonry.
- Stiffens or hardens early.
- Possesses good plasticity.
- An excellent building material.
- Easily workable.

Uses

- Cement mortar
- Making concrete: floor, slab, lintel, beam, column
- Precast pipes, piles
- Water tanks, roads

Properties of Cement

Properties of Cement

Physical Properties

- Fineness of cement
- Soundness
- Consistency
- Strength
- Setting time
- Heat of hydration
- Loss of ignition
- Bulk density
- Specific gravity

Chemical Properties

- Tricalcium aluminate
- Tricalcium silicate
- Dicalcium silicate
- Ferrite
- Magnesia
- Sulphur trioxide
- Iron oxide
- Alkalis
- Free lime
- Alumina

Setting and Hardening of Cement

- Chemical reaction between cement and water is called **Hydration of Cement**
- Cement + water = Sticky Cement paste
- Paste remain in plastic condition for short time
- The phenomenon by which plastic cement changes into solid mass is known as **Setting of cement**
- The phenomenon by which cement paste which is finally set, develop strength is known as **hardening of cement**

Chemical reactions during hydration

- Tricalcium aluminate + gypsum + water ------- ettringite + heat
- Tricalcium silicate + water ---- calcium silicate hydrate + lime + heat
- Dicalcium silicates + water -------- calcium silicate hydrate + lime
- Tricalcium aluminate + ettringite + water ----- monosulfate aluminate hydrate

Setting and Hardening of Cement

Hardened paste consists of the following:

- Ettringite - 15 to 20% (calcium sulfoaluminate) $Ca_6Al_2(SO_4)_3(OH)_{12} \cdot 26H_2O$
- Calcium silicate hydrates, **(C-S-H)** - 50 to 60%
- Calcium hydroxide (lime) - 20 to 25%
- Voids - 5 to 6% (in the form of capillary voids and entrapped and entrained air)

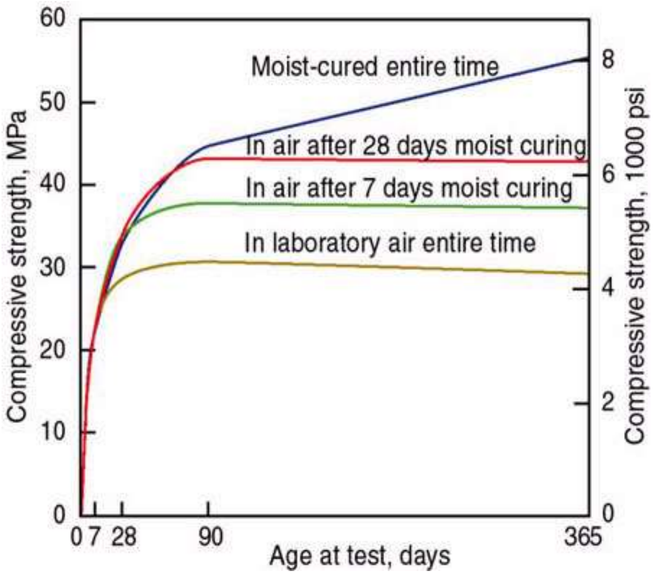


Fig: Compressive strength of cement compounds with age

Types of cements

Portland cement

- Ordinary Portland Cement
- Modified Portland Cement
- Rapid hardening Portland Cement
- Extra Rapid hardening Portland Cement
- Low heat Portland cement
- Sulphate resisting Portland cement
- Water-repellent Portland cement
- Water- Proof Portland cement

Other varieties

- High alumina cement
- Quick setting cement
- Blast furnace slag cement
- Acid resistance cement
- Expanding cement
- Hydrophobic cement

Cement (Chemical Changes)

OPC + Water $\Rightarrow$ Calcium hydroxide ($CaOH_2$) + C-S-H (GEL)

Calcium hydroxide ($CaOH_2$)+ Pozzolana + water → C – S – H (gel)

- PPC is considered equivalent to 33 grade OPC, Strengthwise.
- Some cement brand of PPC is as good as even 53 Grade grade of OPC
- Recently BIS has increased the fly ash content in PPC from 10-25% to 15-35%

Test @ Construction Site

The following are the quality tests on cement at construction site

- Color test
- Presence of lumps
- Adulteration test
- Temperature test
- Float tests
- Strength test
- Setting test
- Date of packing

Tests on cement

The physical tests which are generally performed to determinethe acceptability of cements are

- Fineness Test
- Consistency Test
- Setting time Test
- Soundness Test
- Strength Test
- Heat of Hydration Test
- Specific Gravity Test

Fineness of cement

Fineness of Cement is measured by sieving cement on standard sieve.

The proportion of cement of which the cement particle sizes are greater than the 90 micron is determined.

To determine the number of cement particles larger than 90 µm. or Fineness test of cement. As per **IS: 4031 (Part 1) – 1996.**

The cement of good quality should have less than 10% of wt of cement particles larger than 90 µm. (micron)

Fineness of cement

Procedure for finding Fineness test of cement:

- Take a sample of cement and rub the cement with your hands. The test sample should be free of lumps.
- Now Take 100g of cement and note it as W1.
- Pour 100g of cement in 90 µm sieve and close it with the lid.
- Now place the sieve in Sieve shaking machine. You can also shake the sieve with your hands by Agitating the sieve in planetary and linear movements for 15 minutes.
- Next, weight the residue retained on the 90 µm sieve as W2.
- Then calculate the percentage of Wt of cement-retained on Sieve.
- Repeat the above experiment with three different samples of cement and average the values for accurate results.

Fineness of cement

Setting Time of cement
(IS: 4031 (Part 5) – 1988)

Generally Initial setting is the time elapsed between the moment water is added to the cement to the time at which paste starts losing its plasticity. Final setting time of cement is the time elapsed between the moment the water is added to the cement to the time at which paste has completely lost its plasticity and attained sufficient firmness to resist certain definite pressure.

30 min are given while handling these mixing operations, here fineness of cement and suitable constituents are maintained in such a way that concrete is remained in plastic condition for handling procedures.

Once the concrete is finally placed it should lose its plasticity, so that it is least vulnerable to damages from external agencies. This time should not be more than **10hrs** which is referred as **Final setting time of cement.**

Setting Time of cement
(IS: 4031 (Part 5) – 1988)

To modify the concrete properties i.e to shorten the time of setting or to delay the setting time of cement Admixtures are used and they are as follows:

ACCELERATORS : To shorten the time of setting or increase the rate of hardening or strength development Ex: calcium chloride, Uses: Repair works, precast production, cold weather.

RETARDERS: To delay the setting time of cement Ex: soluble zinc salts gypsum, sugar, carbohydrate derivatives, lignosulphates. Uses: Hot weather.

Soundness Test on Cement

The change in volume of cement after setting or hardening is caused due to the **“unsoundness of cement.”** The expansion of cement after setting causes disruption of the hardened mass and create severe difficulties concerning strength and durability of the structure.

Soundness test of cement is done to ensure that cement doesn’t show any expansion after hardening and to find out the uncombined lime in cement (excess lime). In simple words, this test is conducted to check “unsoundness of cement” Causes of

Unsoundness of cement:-

- Unsoundness is caused due to the presence of excess of lime in cement.
- Inadequate burning at kiln during manufacturing of cement.
- Improper grinding and mixing of raw materials during the production of cement.
- Unsoundness is also caused due to the high proportion of magnesium content or sulphate content.

Soundness Test on Cement

How to prevent unsoundness in cement:-

- Gypsum is added in cement while production to control the rate of hydration in cement. The quantity of gypsum added will vary from 3 to 5 percent depending upon C_3A content. If the addition of gypsum is more than that could be combined with C_3A, an excess of gypsum will remain in the cement in free state. This excess of gypsum leads to an expansion in the hardened state.

About Lechatelier mould:

- It consists of a small split cylinder forming a mould having dimensions of internal dia 30mm and height 30mm. On either side of the split cylinder, two parallel indicating arms with pointed ends of length 165mm is attached.
- Remember, Lechatlier mould is a split cylinder (opened Cylinder) Indicator arms determine the expansion of cement.

Soundness Test on Cement

Procedure:

- Before Performing the test, calculate the standard consistency of cement to find out the water required to obtain the normal consistency(P).
- Now add 0.78 times of water to the cement to give a paste of standard consistency (0.78P).
- Lightly apply oil to the Lechatelier mould and place it on a glass plate.
- Now pour the cement paste into mould and close the mould using lightly oiled glass plate and to avoid misplacement place a weight on it.
- Then, submerge the whole assembly for 24Hrs in water bath at a temperature of 27^0C
- Remove the entire apparatus from water and then calculate the distance separating two indicator points using measuring scale and note it as **L1.**
- Again submerge the whole assembly in a water bath at a temperature of boiling point for 3hours.
- After completion of 3 hours remove the assembly from the bath and measure the distance between two indicator points and note it as **L2.**

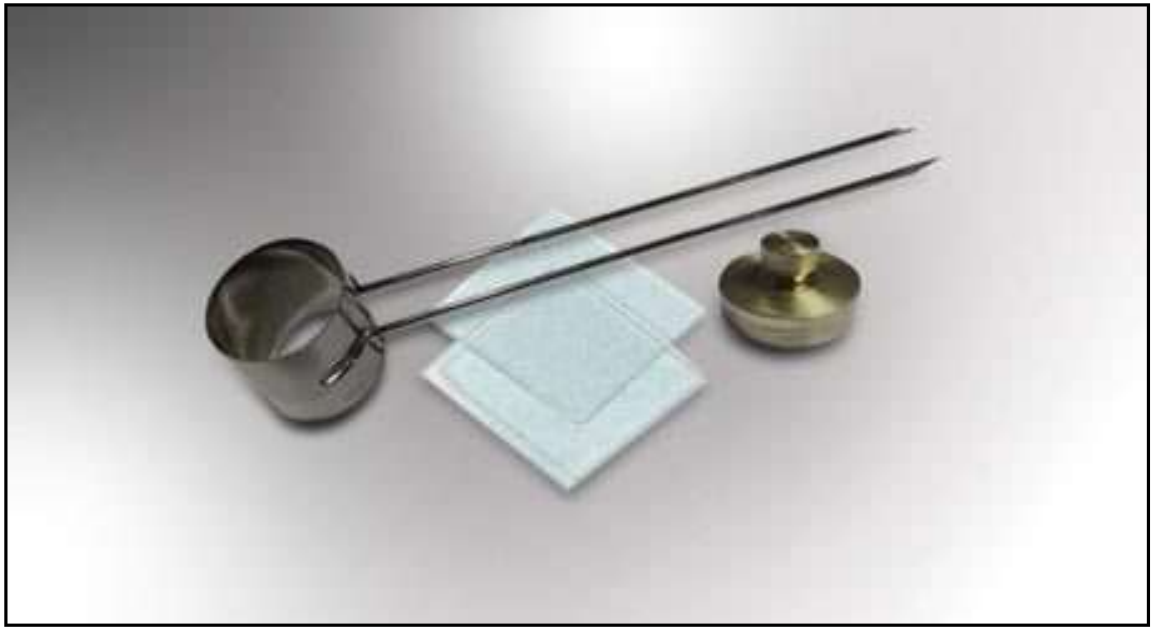
Soundness Test on Cement

A good cement (OPC, PPC, Rapid hardeneing etc) should have not more than below expansion limits.

Types of CementExpansion Limits

- Ordinary Portland cement
  [OPC] 33 Grade, 43 Grade, 53 grade - 10mm
- Portland Pozzolona Cement [PPC] - 10mm
- Rapid Hardening cement - 10mm
- Low heat cement - 10mm
- Super sulphated cement - 5mm

Soundness Test on Cement



https://www.youtube.com/watch?v=je5ztHs9tII

Standard Consistency of Cement

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

Vicat Apparatus Conforming to IS: 5513-1976.

https://www.youtube.com/watch?v=fbQHltWYwjg

Standard Consistency of Cement

Procedure for Standard Consistency of Cement

- Keep the vicat apparatus on a level base (when using vicat apparatus with dashpot, keep the bearing movable rod to its highest position and pin it.) Unscrew the top of the dashpot. Half fill the dashpot with any suitable oil of viscosity and screw the top. Work the plunger a number of times.
- Attach the plunger for determining standard consistency to the movable rod. Work the plunger a number of times.
- Take 400 gm of cement in a pan and a weighed quantity of water in a beaker.
- Prepare a paste with the water added to cement. Start a stopwatch at the time of adding water to cement.
- Keep the vicat mould on a non porous plate and fill the cement paste in it.

Standard Consistency of Cement

- After completely filling the mould, shake it slightly to expel the air. Smooth off the surface of the paste making it level with the top of the moulder. The cement paste thus prepared is the test block.
- Place the test block resting on the non porous plate under the movable rod, bearing the needle.
- Lower the plunger gently to touch the surface of the cement paste and quickly release; (when vicat apparatus with dashpot is used, place the mould filled with cement paste and the non absorbent plate on the base plate of the vicat apparatus. Raise the plunger of the dash pot, bring it in contact with the top cap of the movable bearing rod.

Standard Consistency of Cement

- Remove the pin holding the movable bearing rod to the surface of the cement paste and quickly release by pushing down the plunger to sink in to the paste). This operation shall be done immediately after filling the mould.
- Prepare trial test specimens with varying percentages of water until plunger penetrates to a point 5 to 7mm from the bottom of the vicat mould, which is read on the scale. Express the water required as percentage by weight of the dry cement.

Standard Consistency of Cement

Calculate percentage of water (P) by weight of dry cement required to prepare cement paste of standard consistency by following formula, and express it to the first place of decimal.

Where, $$P = \frac{W}{C} \times 100$$

W = Quantity of water added

C = Quantity of cement used

Hydration & Loss of Ignition

- **Heat of Hydration:** The chemical reaction between cement and water is known as hydration of cement and heat generated in this is known as heat of hydration. It may also be defined as the quantity of heat, in calories per gram in hydrated cement, generated during complete hydration at a given temperature.

- **Loss** on **ignition**. The **loss** on **ignition** of a raw material, **cement** or a clinker sample is the amount of weight **lost** through raising the temperature of the material to a predetermined level. As an indicator it can be used to monitor and improve the quality of the final product.

Loss on ignition is calculated by heating up a cement sample to 900 – 1000°C (1650 – 1830°F) until a constant weight is obtained. The weight loss of the sample due to heating is then determined. A high loss on ignition can indicate prehydration and carbonation, which may be caused by improper and prolonged storage or adulteration during transport or transfer

Specific Gravity & Bulk Density

- The specific gravity is normally defined as the ratio between the weight of a given volume of material and weight of an equal volume of water. The portland cement have a specific gravity of value around 3.15. When it comes to portland pozzolan cements and portland blast furnace cements the value will come near to 2.90 (As per Portland Cement Association (PCA) 1988)

- Bulk density is the weight of material in a given volume. The bulk density of bagged GP (General Purpose) cement isapproximately 1000-1300 kg per cubic meters and, Builders cement is approximately 1000-1250 kg per cubic meters.