CHAPTER 01

Cement

1.1 Introduction

- Cement is an extremely fine material having adhesive and cohesive properties which provide a binding medium for the discrete ingredients.
- The cement is a product obtained by pulverizing (to make into a powder form) clinker formed by calcinating the raw material preliminary consisting of Lime (CaO), Silicate (SiO_2), Alumina (Al_2O_3) and Iron oxide (Fe_2O_3).
- When cement is mixed with water it forms a paste which binds aggregates (fine and coarse) together to form a hard durable mass called concrete.
- The cement which is fine in nature is assume to have good setting property, finer the grains of the cement more is the strength of cement.
- The cement is having good heat of hydration due to which it sets early as compared to other binding material like lime.
- The cement experiences the exothermic chemical reaction when comes in a contact with water.
- The cement is assume to have a specific gravity of 3.15.
- Joseph Asp din manufactured cement and called it Portland cement because when it hardened, it produced a material resembling stone from the quarries near Portland in England.
- During grinding of clinker. "Gypsum or plaster of Paris" is added to prevent flash setting of the cement. The amount of gypsum is about 3 to 5 per cent by weight of clinker. It also improves the soundness of cement.
- The common calcareous materials are lime stone, chalk, marine shell and marl.
- The argillaceous materials are clay, shale, slate and selected blast furnace slag.
- The processes used for the manufacture of cement can be classified as dry and wet.
- The ideal net weight of cement bag is 50 kg and volume of 0.035 m^3.

1.2 Cement and Lime

Following points of differences may be noted between ordinary cement and lime:

1. The cement is used for the gain of early strength whereas lime gains the strength slowly.
2. The cement and lime color are different.

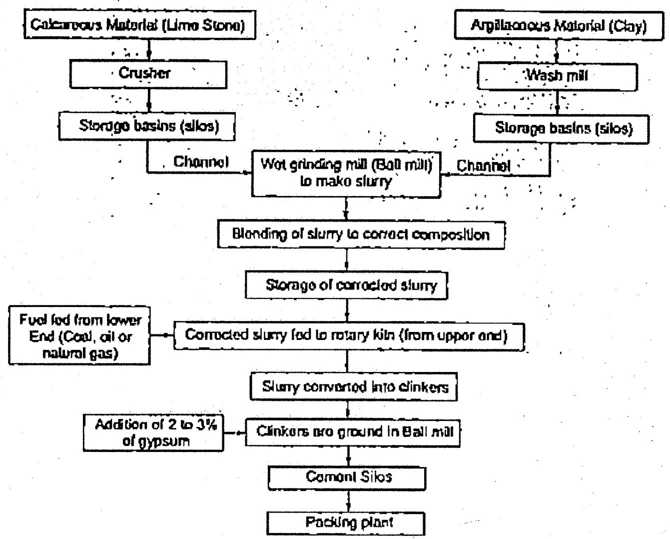
3. The cement and lime both is a binding material having good ultimate strength but lime experiences less early strength as compare to cement.

1.3 Manufacturing of Cement

- The cement is manufactured by integrating the calcareous component and argillaceous component in ratio of 3 : 1.
- The calcareous component can be limestone, chalk, marine shells, marl whereas argillaceous components can be shale, clay, blast furnace slag, slate.
- The calcareous component is used to derive the ingredient called lime whereas the argillaceous component composed of silica, alumina, iron oxide and other impurities.

(a) Wet process:

- It is the old method of manufacturing which is now a days obsoleted.
- It is a costly method of manufacturing because it requires higher degree of fuel consumption, power consumption.
- In this process the preheater is not used.

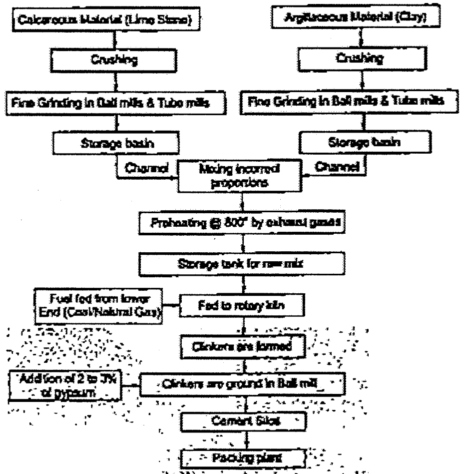


Flow diagram of wet process

(b) Dry process:

- It is a new method of manufacturing which is trending now a days.
- The fuel consumption, power consumption has been reduced to a greater extent by modifying the wet process.

Dry process:



Flow diagram of dry process

- In a dry process, first calcareous components (limestone) and argillaceous component (clay or shale) is reduced in size about 25 mm in a crushers separately in a ball mill or tube mill.

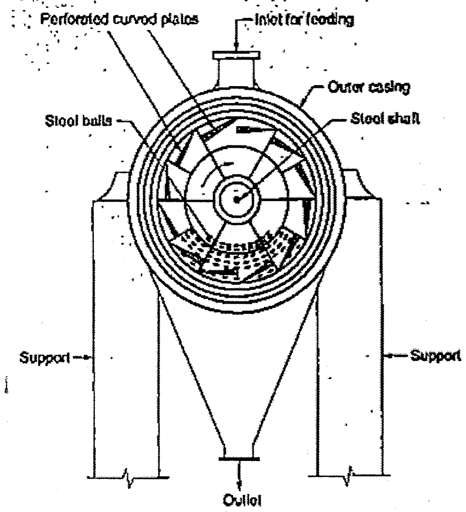


Fig. Vertical Section of a Ball Mill

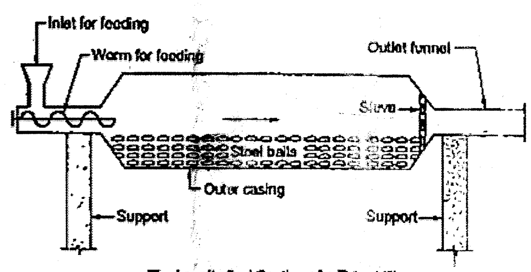


Fig. Longitudinal Section of a Tube Mill

- The calcareous component and argillaceous component after grinding are mixed with each other in a correct proportion and made it ready for next operation in rotary kiln.
- Before feeding into rotary kiln the raw mix is allowed in preheater at a temperature of 850°C which reduces the burning time of raw mix in rotary kiln.

NOTE The crushed material are checked for content of $CaCO_3$, Lime, Alumina, Silica, Fe_2O_3. Any component found short in quarried material is added separately, e.g. Silica is less than crushed sandstone is separately added to raw mix and if lime is less then high grade limestone is crushed and added into raw mix.

- Now, the raw mix after heating for 2-3 hours in preheater, it is allowed to fed into "Rotary Kiln".

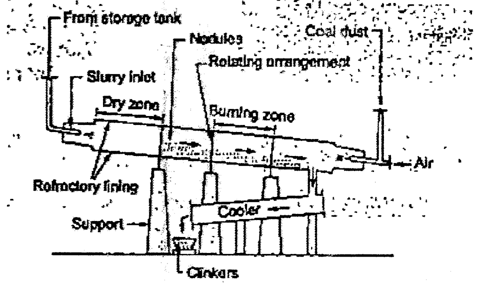


Fig. Rotary Kiln

Diameter = 2.50 to 3 metre
Length = 90 to 120 metre
Volume = 706.3 m^3
Laid Gradient = 1 in 25 to 1 in 30
Revolution = 3 round/min about longer axis.

- **Nodule Zone:** In this zone calcination of limestone occurs and limestone get disintegrated into two parts i.e. lime and carbon dioxide.

$$CaCO_3 \xrightarrow[\text{Calcination}]{\text{Heat}} CaO + CO_2(\uparrow)$$

As the CO_2 is evaporated from the raw mix, the raw mix get converted into nodules.

- **Burning Zone:** In this zone the ingredients of calcareous and argillaceous component i.e. lime, silica, alumina, iron oxide etc. get united with each other at a very high temperature and this process is called fusion.

$$2CaO + SiO_2 \longrightarrow Ca_2SiO_4 = C_2S \text{ (Dicalcium Silicate)}$$

$$3CaO + SiO_2 \longrightarrow Ca_3SiO_5 = C_3S \text{ (Tricalcium Silicate)}$$

$$3CaO + Al_2O_3 \longrightarrow Ca_3Al_2O_6 = C_3A \text{ (Tricalcium Aluminate)}$$

$$4CaO + Al_2O_3 + Fe_2O_3 \longrightarrow Ca_4Al_2Fe_2O_{10} = C_4AF \text{ (Tetra-calcium Alumino-ferrite)}$$

The product obtained from rotary kiln is called clinker which is composed of major compound (Bougue Compound) and Minor Compound i.e. Alkalies (Soda and Potash).

- The clinker composed of (Bougue's compound) and Minor compounds i.e. Alkalies (Soda and Potash)
- The clinker is having flash set property i.e. quick setting property when it comes in contact with moisture. Therefore, the retarder is added to the clinker by its weight i.e. 2 to 3 percent.
- The retarder is admixture which delays the setting time of the cement clinker.
- The ultimately binding material is C – S – H gel i.e. Calcium silicate hydrate gel which is formed when the hydration of cement takes place.

Raw material for cement	Limestone, clay shale (calcareous and argillaceous material)
Oxide composition in raw materials	CaO SiO_2 Al_2O_3 Fe_2O_3
On burning	clinker formed
Compound composition	C_3S C_2S C_3A C_4AF
On	grinding clinker
Portland cements	Various types
On	hydration
Products of hydration	C – S – H gel + $Ca(OH)_2$

1.3.1 Composition of Cement Clinker

Table

The principal mineral compounds in Portland cement	Formula	Name	Symbol	Percentage
1. Tricalcium silicate	$3CaO \cdot SiO_2$	Alite	C_3S	30-50%
2. Dicalcium silicate	$2CaO \cdot SiO_2$	Belite	C_2S	20-45%
3. Tricalcium aluminate	$3CaO \cdot Al_2O_3$	Celite	C_3A	8-12%
4. Tetracalcium alumino ferrite	$4CaO \cdot Al_2O_3 \cdot Fe_2O_3$	Felite	C_4AF	6-10%

- Besides major compounds, minor compounds are also formed that are: Soda (Na_2O) and Potash (K_2O). These two minor compounds i.e. Soda and Potash are responsible for Efflorescence in a cement concrete and cement mortar.

Efflorescence: Efflorescence is the migration of the salt to the surface of porous material, where it forms a coating. This process involves the dissolving of internally held salt in water. The water with the salt migrates to the surface, then evaporates, leaving a coating of salt.

- It is found that ordinary cement achieves **70 percent of its final strength in 28 days and 90 percent in 1 year.**
- The strength in a cement is majorly depends upon the Bougue compound. The properties of Portland cement varies significantly with the proportion of four Bougue compounds.

1. **Tricalcium Silicate C_3S – (30 to 50%)**
   - It is considered as a very good strength compound. It enables the clinker to grind easily.
   - It hydrates rapidly generates high heat and develop early hardness and strength.
   - It increases the resistance to **freezing and thawing.**
   - Rasing of C_3S content beyond specific limit the heat of hydration increases.
   - The hydration of C_3S is mainly responsible for 7 days strength and hardness.
   - The C_3S is responsible not only for the gain of strength at early days but contributes considerably upto 28 days.
   - It is the only compound which has maximum contribution in 28 days strength, it is responsible for gain of strength from 24 hours to 28 days where it contributes (max) upto 14 days.
   - The heat of hydration is 500 J/gm.
2. **Dicalcium Silicate C_2S – (20 to 45%)**
   - It hydrates and hardens slowly and takes long time to add to the strength. It is responsible for **ultimate strength.**
   - It **imparts resistance to chemical attack.**
   - Raising C_2S content in cement reduces the **early strength.**
   - Raising C_2S content, decreases the resistance to freezing and thawing at early ages and decreases heat of hydration.
   - At early days C_2S has little influence on strength and hardness, where after a year its contribution is same as C_3S in strength and hardness.
   - The C_2S is a stable compound because in a low heat cement C_2S content is more as low heat cement is stable cement with respect to durability of structure.
   - The contribution of C_2S starts from 14 days and remains upto 1 year and or so.
   - After 28 days the gain of strength is due to C_2S.
   - The heat of hydration 260 J/gm.
3. **Tricalcium Aluminate C_3A (8 to 12 %)**
   - It rapidly reacts with water and is responsible for flash set of finely grounded clinker.
   - The flash set property of cement clinker is prevented by adding a retarder gypsum 2% to 3%.
   - Least stable compound because it is responsible for maximum heat of hydration and very less durable with respect to susceptible cracks in structure.
   - Any cement having C_3A content more is liable for sulphur attacks.
   - It contributes in 24 hours strength after addition of water but it contribute less.
   - It has heat of hydration 865 J/gm.
4. **Tetra-calcium Aluminate Ferrite C4AF (6– 10%)**
   - It is also responsible for high heat of hydration as compare to C_2S and but less than C_3A.
   - Its contribution in strength is very less.
   - It is having contribution within 24 hours of adding water to the cement.
   - The heat of hydration 420 J/gm.

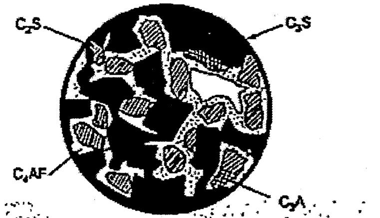


Fig. Schematic representation of the composition of Portland cement

NOTE

- The rate of hydration is increased by an increase in fineness of cement. However, total heat evolved is the same. The rate of hydration of the principal compounds is shown in figure and will be in the following descending order. $C_4AF > C_3A > C_3S > C_2S$

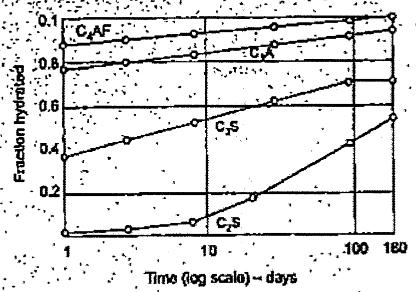


Fig. Rate of Hydration of Pure Compounds

- Rate of heat evolution of Bougue compound, if equal amount of each is considered will be in following descending order

  C_3A (865 J/gm) > C_3S (865 J/gm) > C_3AF (420 J/gm) > C_2S (260 J/gm).

Compound	Heat of hydration at the given age (J/g)		
	3 days	90 days	13 years
C_3S	242.44	434.72	509.96
C_2S	50.16	175.56	246.62
C_3A	886.15	1299.98	1354.32
C_4AF	288.42	409.64	426.36

Heat of Hydration

• Development of strength of four Bougue compounds of cement with age

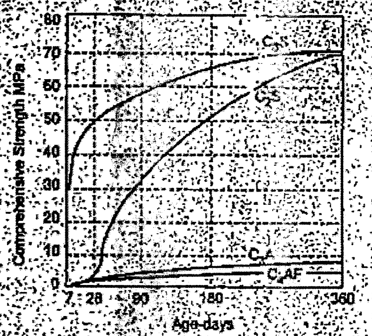


Fig. Development of Strength of Pure Compounds

1.3.2 Functions of Various Cement Ingredients

- The relative proportions of thee oxide compositions are responsible for influencing the various properties of cement.
- Consequently, free lime will exist in the clinker and will result in an unsound cement. An increase in silica content at the expense of alumina and ferric oxide makes the cement difficult to fuse and form clinker.
- Rate of setting of cement paste is controlled by regulating the ratio $SiO_2/(Al_2O_3 + Fe_2O_3)$
- When development of heat of hydration is undesirable, the silica content is increased to about 21 per cent. and the alumina and iron oxide contents are limited to 6 per cent each.
- Resistance to the action of sulphate waters is increased by raising further the silica content to 24 per cent and reducing the alumina and iron contents in 4 per cent each.
- Small percentage of iron oxide renders the highly siliceous raw materials easier to burn.

Table

Constituents	Percentage	Average percentage
Lime (CaO)	62 to 67%	62
Silica (SiO_2)	17 to 25%	22
Alumina (Al_2O_3)	3 to 8%	5
Calcium Sulphate ($CaSO_4$)	3 to 4%	4
Iron oxide (Fe_2O_3)	3 to 4%	3
Magnesia (MgO)	0.1 to 3%	2
Sulphur	1 to 3%	1
Soda and Potash ($Na_2O + K_2O$)	0.5 to 1.3%	1

1. **Lime (CaO):** This is the important ingredient of cement and its proportion is to be carefully maintained. The lime in excess makes the cement unsound and causes the cement to expand and disintegrate. On the other hand, if lime is in deficiency, the strength of cement is decreased and it causes cement to set quickly.
2. **Silica (SiO_2):** This is also an important ingredient of cement and it imparts strength to the cement due to the formation of dicalcium and tricalcium silicates. If silica is present in excess quantity, the strength of cement increases but at the same time, its setting time gets prolonged.
3. **Alumina (Al_2O_3):** This ingredient imparts quick setting property to the cement. It acts as a flux and it lowers the clinkering temperature. However high temperature is essential for the formation of a suitable type of cement and hence the alumina should not be present in excess amount as it weakens the cement.
4. **Calcium Sulphate ($CaSO_4$):** This ingredient is in the form of gypsum and its function is to increase the initial setting time of cement.
5. **Iron Oxide (Fe_2O_3):** This ingredient imparts colour, hardness and strength to the cement.
6. **Magnesia (MgO):** This ingredient, if present in small amount, imparts hardness and colour to the cement. A high content of magnesia makes the cement unsound.
7. **Sulphur (S):** A very small amount of sulphur is useful in making sound cement. If it is in excess, it causes unsoundness in cement.
8. **Alkalies:** The most of the alkalies present in raw materials are carried away by the flue gases during heating and the cement contains only a small amount of alkalies. If they are in excess in cement, they cause a number of troubles such as alkali-aggregate reaction, efflorescence and staining when used in concrete, brickwork or masonry morter.

1.4 Hydration of Cement

- The chemical reactions that take place between cement and water is referred to as hydration of cement.
- The hydration of cement can be visualized in two ways viz. "through solution" and "solid state" type of mechanisms
- The reaction of cement with water is exothermic i.e. it liberates a considerable quantity of heat and this liberated heat is called as heat of hydration.
- The hydration process is not an instantaneous one. The reaction is faster in the early periods and continues indefinitely at a decreasing rate.
- During hydration, C_3S and C_2S react with water and calcium silicate hydrate (C-S-H) is formed along with calcium hydroxide $[Ca(OH)_2]$.
- Calcium silicate hydrate is the most important product of hydration and it determines the good properties of concrete.
- $2(3CaO \cdot SiO_2) + 6H_2O \rightarrow 3CaO \cdot 2SiO_2 \cdot 2H_2O + 3Ca(OH)_2$

or it can be written as:

$$2C_3S + 6H \rightarrow C_3S_2H_3 + 3Ca(OH)_2$$
$$100 + 24 \rightarrow 75 + 49$$

The corresponding weights involved are

Similarly,

$$2(2CaO \cdot SiO_2) + 4H_2O \rightarrow 3CaO \cdot 2SiO_2 \cdot 3H_2O + Ca(OH)_2$$

or it can be written as:

$$2C_2S + 4H \rightarrow C_3S_2H_3 + Ca(OH)_2$$
$$100 + 21 \rightarrow 99 + 22$$

The corresponding weights involved are:

$$2C_3S + 6H \longrightarrow C_3S_2H_3 + 3Ca(OH)_2$$

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

Table : Permissible Limits for Impurities in Water

Impurity	Permissible Limits
Organic	200 mg/l
Inorganic	3000 mg/l
Sulphates (SO_4^{-2})	400 mg/l
Chlorides (Cl^-)	2000 mg/l for plain concrete work, 500 mg/l for reinforced concrete work
Suspended matter	2000 mg/l

- It can be seen from the above reactions that C_3S produces a comparatively less quantity of calcium silicate hydrate and more quantity of calcium hydroxide than that formed in the hydration of C_2S.
- Calcium hydroxide is not a desirable product in the concrete mass as it is soluble in water and gets leached out thereby making the concrete porous, particularly in hydraulic structures.
- C_2S reacts rather slowly and it is responsible for strength of concrete at later stage. It produces less heat of hydration.
- The lack of durability of concrete is on account of the presence of calcium hydroxide.
- The calcium hydroxide also reacts with sulphates present in soils or water to form calcium sulphate which further reacts with C_3A and cause deterioration of concrete. This is known as **sulphate attack.**
- The only advantage of calcium hydroxide is that being alkaline in nature it maintains pH value around 13 in the concrete which resists the corrosion of reinforcements.
- From the view point of hydration, it is convenient to discuss C_3A and C_4AF together because the products formed in the presence of gypsum are similar. Gypsum and alkalies go into solution quickly and the solubility is depressed. Depending upon the concentration of aluminate and sulphate ions in the solution, the precipitating crystalline product is either calcium aluminate trisulphate hydrate or calcium aluminate monosulphate hydrate. The calcium aluminate trisulphate hydrate is known as Ettringite.
- It has been estimated that on an average 23% of water by weight of cement is required for chemical reaction with Portland cement compounds. This 23% of water chemically combines with cement, and therefore it is called as bound water.
- A certain quantity of water is imbibed within the gel pores. This water is known as gel water. The bound water and gel water are complimentary to each other.
- It has been estimated that about 15% water by weight of cement is required to fill up the gel pores.
- Therefore, a total of 38% of water by weight of cement is required for the complete chemical reactions and occupy the space within gel pores.
- If water equal to 38% by weight of cement is only used then it can be noticed that the resultant paste will undergo full hydration and no extra water will be available for the formation of undesirable capillary cavities.
- **If more than 38% of water is used, then excess water will cause undesirable capillary cavities which ultimately reduces the strength of the cement concrete.**

1.5 Type of Cements

There are different types of cement as classified by the Bureau of Indian Standards (BIS):

(i) Ordinary Portland Cement
 (a) 33 grade – IS : 269-1989
 (b) 43 grade – IS : 8112-1989
 (c) 53 grade – IS : 12269-1987
(ii) Rapid Hardening Cement – IS : 8041-1990
(iii) Extra Rapid Hardening Cement
(iv) Low Heat Portland Cement – IS : 12600-1989
(v) Portland Slag Cement – IS : 455-1989
(vi) Portland Pozzolana Cement – IS : 1489-1991(Part 1 and 2)
(vii) Sulphate Resisting Portland Cement – IS : 12330-1988
(viii) White Portland Cement – IS : 8042-1989
(ix) Coloured Portland Cement – IS : 8042-1989
(x) Hydrophobic Cement – IS : 8043-1991
(xi) High Alumina Cement – IS : 6452-1989
(xii) Super Sulphated Cement – IS : 6909-1990
(xiii) Special Cements
 (a) Masonry Cement
 (b) Air Entraining Cement
 (c) Expansive Cement
 (d) Oil Well Cement

1.5.1 Ordinary Portland Cement (OPC)

- It is obtained by Pulverizing argillaceous and calcareous material in correct proportion.
- Portland cement is most common variety of artificial cement and most commonly known as O.P.C. (Ordinary Portland Cement).
- It is available in 3 grades:
 (a) OPC–33 grade (IS: 269–989)
 (b) OPC-43 grade (IS : 8112–1989)
 (c) OPC–53 grade (IS: 12269–1987
- The number 33, 43, 53 corresponds to 28 days characteristic compressive strength of cement as obtained from standard test on cement sand mortar (1 : 3) specimens.
- The OPC 33 is recommended for concrete mix having strength upto 20 N/mm^2 i.e. M20.
- These are most commonly used in general concrete construction, where there is no exposure to sulphates.
- Due to high fineness, the workability of concrete increases for a given water-cement ratio. IS10262 has classified the OPC gradewise from "A to F" based on 28 days compressive strength as follows:

Table

Category	Strength (MPa)
A(OPC 33)	32.5 – 37.5
B(OPC 33)	37.5 – 42.5
C(OPC 43)	42.5 – 47.5
D(OPC 43)	47.5 – 52.5
E(OPC 53)	52.5 – 57.5
F(OPC 53)	57.5 – 62.5

- It is presently available in three different grades viz. OPC 33, OPC 43 and OPC 53. The numbers 33, 43 and 53 correspond to the 28 days (characteristic) compressive strength of cement as obtained from standard tests on cement-sand mortar specimens.
- It is used in general concrete construction where there is no exposure to sulphates in the soil or in ground water.

1.5.2 Rapid Hardening Cement (RHC)

- It is finer than ordinary Portland cement.
- It contains more C_3S and less C_2S than the OPC.
- The 1 day strength of this cement is equal to the 3 days strength of OPC with the same water cement ratio.
- The main advantage of rapid hardening cement is that shuttering may be removed much earlier, thus saving considerable time and expenses.
- Rapid hardening cement is also used for road work where it is imperative to open the road traffic with the minimum delay.
- Cost of Rapid hardening cement is nearly 10–15% more than OPC.
- It can be safely exposed to frost as it matures more quickly.

1.5.3 Extra Rapid Hardening Cement (ERHC)

- It is obtained by mixing calcium chloride (not exceeding 2% by weight of the rapid hardening cement) with rapid hardening cement.
- Addition of $CaCl_2$ imparts quick setting properties in extra rapid hardening cement.
- The acceleration of setting, hardening and evolution of heat in the early period of hydration makes this cement very suitable for concreting in cold weathers.
- The 1 or 2 day strength of extra rapid hardening cement is 25% more than that of rapid hardening cement.
- The gain of strength disappears with age and 90 days strength of extra rapid hardening cement and rapid hardening cement are nearly the same.
- Use of extra rapid hardening cement is prohibited in prestressed concrete construction.
- Maximum time of using this cement is 20 minute for mixing, transporting, placing and compaction.

1.5.4 Low Heat Cement (LHC)

- It is a Portland cement which is obtained by reducing the more rapidly hydrating compounds, C_3S and C_3A and increasing C_2S.
- As per the Indian Standard specifications, the heat of hydration of low-heat cement shall be as follows:

  7 days – not more than 65 calories per gm

  28 days – not more than 75 calories per gm
- Since the rate of gain of strength of this cement is slow, hence adequate precaution should be taken in its use such as with regard to removal of formwork, etc.
- LHC is used in massive construction works like abutments, retaining walls, dams, etc. where the rate at which the heat can be lost at the surface is lower than at which the heat is initially generated.
- It has low rate of gain of strength, but the ultimate strength is practically the same as that of OPC.

1.5.5 Portland Blast Furnace Slag Cement

- This cement is made by intergrinding Portland cement clinker and granulated blast furnace slag.
- The proportion of the slag being not less than 25% or more than 65% by weight of cement.
- The slag should be granulated blast furnace slag of high lime content, which is produced by rapid quenching of molten slag obtained during the manufacture of pig iron in a blast furnace.
- In general blast furnace slag cement is found to gain strength more slowly than the ordinary Portland cement.
- The heat of hydration of Portland blast furnace slag cement is lower than that of OPC. So this cement can be used for mass concreting but is unsuitable for cold weather.
- It has fairly high sulphate resistance, rendering it suitable for use in environments exposed to sulphates (in the soil or in ground water).
- It is used for all purpose for which ordinary Portland cement is used.
- Because of its low heat evolution, it can be used in mass concrete structure such as dams, foundations and bridge abutments.

1.5.6 Portland Pozzolana Cement (PPC)

- It can be produced either by grinding together Portland cement clinker and pozzolana with the addition of gypsum or by blending uniformly Portland cement and fine pozzolana.
- As per the latest amendment, the proportion of pozzolana may vary from 15 to 35% by weight of cement clinker. Earlier, it was 10 to 25%.
- A pozzolanic material is essentially a siliccious or aluminous material which in itself possess no cementitious properties, which in finely divided form and in the presence of water reacts with calcium hydroxide, liberated in the hydration process at ordinary temperature to produce compounds possessing cementitious properties. This is known as pozzolanic action i.e.

$$Ca(OH)_2 + \text{Pozzolana} + \text{Water} \longrightarrow \text{C-S-H(gel)}$$

- The pozzolanic materials generally used for manufacture of Portland pozzolana cement are calcined clay (IS : 1489 part 2 of 1991) or fly ash (IS: 1489 part 1 of 1991).
- Fly ash is a waste material generated in a thermal power station, when powdered coal is used as a fuel.
- PPC produces less heat of hydration and offers great resistance to the attack of impurities in water than OPC.
- PPC is particularly useful in marine and hydraulic constructions, and other mass concrete structures
- The disadvantage of using PPC is that the reduction in alkalinity reduces the resistance to corrosion of steel reinforcement. But considering the fact that PPC significantly improves the permeability of concrete, thereby increases the resistance to corrosion of reinforcement.
- This cement has higher resistance to chemical agencies and to sea water because of absence of lime.
- It evolves less heat and its initial strength is less but final strength (28 days onward) is equal to OPC.
- It has lower rate of development of strength than OPC.

- The average compressive strength of cement mortar (1 : 3) at
  - (i) at 1 day ± 1 hr 16 MPa (Minimum)
  - (ii) at 7 day ± 2 hr 22 MPa (Minimum)
  - (iii) at 28 day ± 4 hr 33 MPa (Minimum)

1.5.7 Acid Resistant Cement (ARC)

- An acid resistant cement is composed of the following:
  - (i) Acid resistant aggregates such as quartz, quartzites, etc.
  - (ii) Additive such as Na_2SiF_6 (This accelerates hardening).
  - (iii) Solution of sodium silicate or soluble glass (sodium silicate is a binding material).
- The addition 0.5% of linseed oil or 2% of cerussite increases resistance to water also.

1.5.8 Sulphate Resisting Cement (SRC)

- The Portland cement with low C_3A and C_4AF and ground finer than OPC is known as sulphate resisting cement and generally C_3S and C_2S kept about 45 % each.
- This cement is sulphate-resistant because the disintegration of harden concrete caused by the chemical reaction of C_3A with soluble sulphate lime $MgSO_3$, $CaSO_3$ and Na_2SO_3 is inhibited.
- The setting time are same as that of OPC
- The compressive strength of the cubes should be as follows:

  3 Day ± 1 hr = 10 N/mm²

  7 Day ± 2 hr = 16 N/mm²

  28 Day ± 4 hr = 33 N/mm²
- This cement is "sulphate resistant" because the disintegration of concrete caused by the reaction of C_3A in hardened cement with a sulphate salt from outside is inhibited.
- It is used in marine structures, sewage treatment works, and in foundations and basements where soil is infested with sulphates.
- However, recent research indicates that the use of sulphate resisting cement is not beneficial in environments where chlorides are present.

1.5.9 Coloured Cement (White Cement)

- The process of manufacturing white cement is the same but the amount of iron oxide which is responsible for greyish colour is limited to less than 1 per cent.
- Sodium Alumino Ferrite (Cryolite) Na_3AlF_6 is added to act as flux in the absence of iron oxide.
- The properties of white cement is nearly same as OPC.
- Whiteness of white cement is measured by ISI scale or Hunter's scale.
- The whiteness should not be less than 70% on ISI scale and on Hunter's scale it is generally 90%.
- The strength of white cement is much higher than what is stated in IS : 8042-1989, the code for white cement.
- Grey colour of OPC is due to the presence of iron oxide. Hence in white cement, Fe_2O_3 is limited to 1%. Sodium Alumino Ferrite (Cryolite) Na_3AlF_6 is added to act as flux in the absence of iron oxide.

1.5.10 High Alumina Cement (HAC)

- It is very different in composition from Portland cement.
- In this cement the C_3A content is very low due to which it is resistant to sulphur attacks and chemical attacks.
- Its sets quickly and attains higher ultimate strength in a short period. Its strength after 1 day is about 40 N/mm² and that after 3 days is about 50 N/mm².
- It is characterized by its dark colour, high early strength, high heat of hydration.
- The raw materials used for its manufacture consists of limestone (or chalk) and bauxite which is a special clay with high alumina content.
- The bauxite is an aluminium ore. It is specified that total alumina content should not be less than 32 per cent and the ratio by weight of alumina to the lime should be between 0.85 and 1.30.
- It is resistant to freezing and thawing.
- It has an initial setting time of 3.5 hours and final setting time of about 5 hours.
- High alumina cement is very expensive to manufacture.
- It is used where early removal of the formwork is required.
- Its rapid hardening properties arise from the presence of calcium aluminate, chiefly monocalcium aluminate (Al_2O_3. CaO), as the predominant compound in place of calcium silicates of Portland cement and for setting and hardening there is no free hydrated lime as in the case of Portland cement.
- It must not be mixed with any other type of cement.

1.5.11 Quick Setting Portland Cement

- In the manufacture of this cement, gypsum content is reduced to get the quick setting property. Also small amount of aluminium sulphate is added.
- It is ground much finer than OPC.
- It sets quickly but does not harden quickly.

  Initial setting time = 5 minutes, Final setting time = 30 minutes.
- It is used when concrete is to be laid under water.

1.5.12 Masonry Cement (IS: 3466)

- Masonry cement consists of a mixture of Portland cement or blended hydraulic cement and plasticizing materials (such as limestone or hydrated or hydraulic lime) together with other materials introduces to enhance one or more properties such as setting time, workability, water retention, and durability.
- Addition of these materials gives good workability, reduces shrinkage and water retentivity.
- This cement is used for masonry works, plaster work etc.
- This cement must not be used for concrete work but used far Masonry construction.
- Masonry cement when used for making mortar, incorporates all the good properties of lime mortar and discards all the non ideal properties of cement mortar.

1.5.13 Super Sulphated Cement (SSC)

- It is made from well granulated blast furnace slag (80-85%), calcium sulphate (10-15%) and Portland cement (1-2%) and is ground finer than the Portland cement.
- In this cement C_3A, which is susceptible to sulphates is limited to less than 3.5%.

- Sulphate resisting cement can also be produced by the addition of extra iron oxide before firing this combines with alumina which would otherwise form C_3A, instead forming C_4AF which is not affected by sulphates.
- It should be used in places with temperature is below 40°C.
- Compressive strength should be as follows:
  3 Day ± 1 hr = 15 N/mm²
  7 Day ± 2 hr = 22 N/mm²
  28 Day ± 4 hr = 30 N/mm²
- It has low heat of hydration.
- It is used for construction of dams and other mass concreting works.
- Concrete made from super sulphated cement may expand if cured in water and may shrink if the concrete is cured in air.
- It has high resistance to chemical attack.

1.5.14 Air Entraining Cement (AEC)

- This cement is made by mixing a small amount of an air entraining agent with OPC clinker at the time of grinding.
- It is manufactured by mixing a small amount of air entraining agent i.e. 0.1% to 0.3% with OPC clinker at time of grinding.
- It offers good workability due to which it is having higher initial setting time than OPC.
- It is having lesser final setting time as compared to OPC, due to which it offers resistance to freezing and thawing.
- Air entrainment improves workability and w/c ratio can be reduced which in turn reduces shrinkage etc.
- It is yet not been covered by Indian Standard so far.
- Some of the air entraining agents are:
  (i) Alkali salts of wood resins.
  (ii) Synthetic detergents of the alkyl-aryl sulphonate type.
  (iii) Calcium lignosulphate.
- It produces tough, tiny, discrete, non-coalescing air bubbles at the time of mixing in the body of concrete which will modify the properties of plastic concrete with respect to workability, segregation and bleeding.

1.5.15 Hydrophobic Cement

- It is obtained by intergrinding OPC with 0.1 – 0.4 per cent of water repellant film-forming substance such as oleic acid or stearic acid.
- The water repellant film formed around each grain of cement reduces the rate of deterioration of the cement during long storage, transportation, or under unfavourable conditions.
- The properties of hydrophobic cement are nearly the same as that of OPC.
- The cost of this cement is nominally higher than OPC.
- Hydrophobic cement also features greater water resistance and water impermeability.

1.6 Field Tests for Cements

- Colour: Grey colour with a light greenish shade.
- Physical Properties: Cement should feel smooth when rubbed in between the fingers.
- If hand is inserted in a bag or heap of cement, it should feel cool.
- If a small quantity of cement is thrown in a bucket of water, it should sink and should not float on the surface.
- Presence of lumps: Cement should be free from lumps.

1.7 Laboratory Tests for Cements

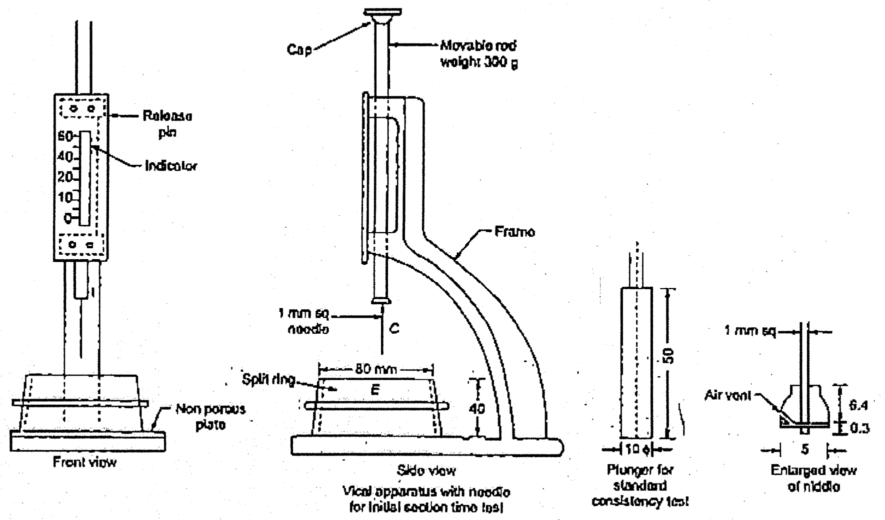
- Tests on cement are performed in accordance with IS : 4032-1985 and IS : 4031 (Parts 1 to 15)-1988-99 to assess the following:
  (i) Chemical composition
  (ii) Normal (standard) consistency
  (iii) Initial and final setting times
  (iv) Soundness
  (v) Strength
  (vi) Fineness
  (vii) Heat of hydration
  (viii) Specific gravity

1.7.1 Chemical Composition Test

- Ratio of percentage of lime to percentage of silica, alumina and iron oxide known as Lime Saturation Factor (LSF), when calculated by the formula $\frac{CaO - 0.7SO_3}{(2.8SiO_2 + 1.2Al_2O_3 + 0.65Fe_2O_3)}$ shall not be greater than 1.02 and not less than 0.66.
- Ratio of percentage of alumina (Al_2O_3) to that of iron oxide (Fe_2O_3) shall not be less than 0.66
- Weight of insoluble residue shall not be more than 4 per cent.
- Weight of magnesia shall not be more than 6 per cent.
- Total loss on ignition shall not be more than 5 per cent.
- Total sulphur content calculated as sulphuric anhydride shall not be more than 2.5% when C_3A is 5% or less and shall not be more than 3% when C_3A is more than 5%.

1.7.2 Normal Consistency Test

- The normal (standard) consistency of a cement paste is defined as that consistency which will permit a Vicat plunger having 10 mm diameter and 50 mm length to penetrate a depth of 33 to 35 mm from the top (or 5 to 7 mm from the bottom) of the mould.



Front view

Side view

Vicat apparatus with needle for initial section time test

Plunger for standard consistency test

Enlarged view of niddle

Vicat Apparatus:

- Vicat apparatus assembly consists of a plunger 300 gm in weight with a length of 50 mm and diameter of 10 mm and a mould which is 40 mm deep and 80 mm in diameter.
- There are two attachments for the plunger viz.:
  (i) A square needle with 1 mm² cross-section which is attached to the plunger for initial setting time test.
  (ii) A needle with an annular collar of 5 mm diameter which is used for final setting time.

Test Procedure:

- To prepare the paste, take weighed quantity (300 g) of cement and place it in a crucible.
- Mix a weighed quantity of water (approximately 24% by weight of cement) for the first trial.
- The time of mixing or gauging should not be less than 3 minutes nor more than 5 minutes and gauging time should be counted from the time of adding water to the dry cement until commencing to fill the mould.
- The Vicat mould is filled with the paste, which is levelled off at its top.
- The mould is placed under the Vicat plunger.
- The vicat plunger is brought down to touch the surface of paste in the mould and quickly released allowing it to sink into the paste by its own weight.
- Take the reading by noting the depth of penetration of the plunger.
- Similarly conduct the trials with increasingly water/cement ratios till such time the plunger penetrates for a depth of 33 to 35 mm from the top (or 5 to 7 mm from the bottom).
- That particular percentage of water which allows the plunger to penetrate only to a depth of 33 to 35 from the top (or 5 to 7 mm from the bottom) is known as the percentage of water required to produce a cement paste of normal (standard) consistency.
- This percentage is generally denoted by *P*.
- This test should be conducted at a constant temperature of 27° ± 2°C and a constant humidity of 90%.

1.7.3 Initial Setting Time Test

- It is the time elapsed between the moment that the water is added to the cement, to the time that the paste starts losing its plasticity.
- The test procedure is as follows:
  (i) Take 300 gm of cement and make a cement paste of consistency 0.85 *P*
  (ii) Attach the square needle to the Vicat plunger and lower it gently to make contact with the surface of test block and quickly release it.
  (iii) When the needle penetrates only to a depth of 33 to 35 mm from the top (or 5 to 7 mm from the bottom), the test is completed.
- Initial setting time should not be less than 30 minutes for OPC and 60 minutes for low heat cement.

1.7.4 Final Setting Time Test

- The final setting time is the time elapsed between the moment the water is added to the cement and the time when the paste has completely lost its plasticity and has attained sufficient firmness to resist certain definite pressure.
- The test procedure is as follows:
  (i) Take 300 gm of cement and make a cement paste of consistency of 0.85 *P*.
  (ii) Replace the square needle by a needle with annular collar.
  (iii) Lower the attachment to gently cover the surface of test block.
  (iv) If the needle makes an impression, while the annular collar of the attachment fails to do so, the cement is considered to be finally set. Thus, the paste has attained such hardness that the needle does not pierce through the paste more than 0.5 mm.
- The final setting time should not be more than 10 hours.

NOTE

Significance of initial and final setting time:

(a) Concrete once place should not be disturbed till final setting has take place.
(b) The transportation of concrete from the place where concrete is prepared to the placing of concrete required some finite time that should be within the initial setting time.
(c) Final setting time test is done because the concretre should achieve the desired strength as early as possible so that the shuttering can be removed and reused.

1.7.5 Soundness Test

- Soundness of cement indicates that the cement paste, once it has set, does not undergo appreciable change in volume causing concrete to crack.
- The cement having some quantity of free lime, magnesia and excess sulphates undergoes large changes in volume as the time elapses tending to cause cracks.
- The soundness of cement is determined either by 'Le Chatelier's method' or by means of 'Autoclave' test.

- No satisfactory test is available for assessment of soundness due to excess of calcium sulphate, but its content can be easily determined by chemical analysis.

(a) Le Chatelier's Method:

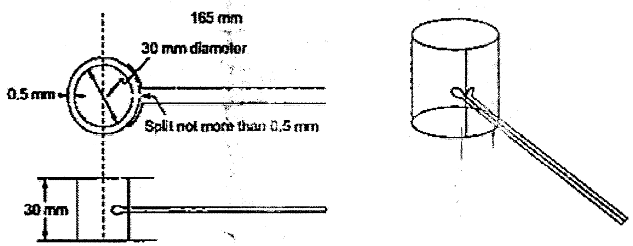
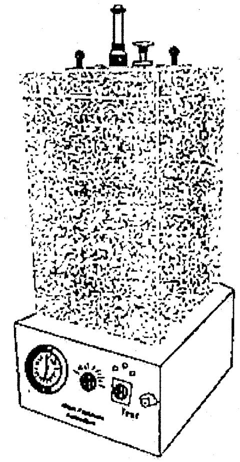


Fig. Le-Chatelier apparatus for finding soundness of cement

- The Le Chatelier's apparatus consists of a small split cylinder of spring brass. It is 30 mm in diameter and 30 mm high. On either side of the split are attached two indicator arms 165 mm long with pointed ends.
- Take 100 gm of cement and make a cement paste of consistency 0.78 *P*.
- Fill the cement paste in the mould and keep it on a glass plate.
- Cover the mould on the top by another glass plate.
- The whole assembly is immersed in water at a temperature of 27°-32°C and kept there for 24 hours.
- The assembly is taken out after 24 hours and the distance between the indicator points is measured.
- The mould is then immersed in a water bath.
- The water of the bath is brought to boiling point with the mould submerged in 25 to 30 minutes and kept boiling for 3 hour.
- The mould is taken out from water and allowed to cool.
- Distance between the points is then measured.
- The difference between the two measurement represents the expansion of cement.
- The Le Chatelier's method detects unsoundness due to free lime only.
- This method of testing does not indicate the presence and after effect of the excess of magnesia and calcium sulphate.
- The expansion of cement must not exceed 10 mm for OPC, rapid hardening and low heat Portland cements by this method.
- OPC, Rapid Hardening Cement, Low Heat Cement, PPC can have maximum expansion less than 10 mm whereas high alumina cement and super sulphated cement can have maximum expansion less than 5 mm.

(b) Autoclave Test:

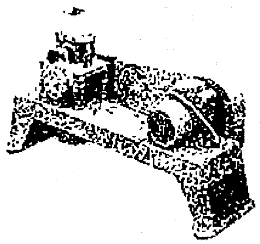
- Indian Standard specification recommends that a cement having a magnesia content of more than 3 per cent shall be tested for soundness by autoclave test which is sensitive to both free magnesia and free lime.



- In this test, a cement paste of 25 mm × 25 mm × 250 mm is placed in a standard autoclave.
- Now, the steam pressure inside the autoclave is raised at such a rate so as to bring the gauge pressure of the steam to 21 kg/cm^2 in 1 hour to 1 hour 15 minutes from the time the heat is turned on.
- This pressure is maintained for three hours.
- The autoclave is cooled and length of the specimen is measured again.
- The expansion should not exceed 0.8%.
  - For OPC (33, 43, 53); SRC; PPC, RHC, LHC, Slag cement
  - 1% for masonry cement.

1.7.6 Strength Test

(a) Compressive Strength Test:



- The compressive strength of the hardened cement is the most important of all the properties.
- Take 185 gm of standard sand (Ennore sand), 55 gm of cement (i.e. ratio of cement to sand is 1: 3) and mix them with a trowel for one minute.
- Add water of quantity $\left(\frac{P}{4}+3.0\right)$% of combined weight of cement and sand where P is the percentage of water required to produce a cement paste of normal consistency.
- This time of mixing should not be less than 3 minutes and not more than 4 minutes.
- Immediately, after mixing, the mortar is filled in a cube mould of size 7.06 cm. The area of the face of cube should be 50 cm^2.
- Compact the mortar either by hand compaction in a standard specified manner or on the vibrating equipment for 2 minutes. (vibrations = 1200 ± 400 vibrations/minute)
- Keep the compacted cube in the mould at a temperature of 27° ± 2°C and at least 90% relative humidity for 24 hours.
- After 24 hours, the cubes are removed from the mould and immersed in clean fresh water until taken out for testing.
- Three cubes are tested for compressive strength at 1 day, 3 days, 7 days and 28 days where the period of testing being reckoned from the completion of vibration.
- The compressive strength shall be the average of the strengths of the three cubes for each period respectively.
- The compressive strength of 33 grade OPC at 3 days, 7 days and 28 days is 16 MPa, 22 MPa and 33 MPa respectively.
- Load applied gradually as 0 to 35 N/mm^2/min on cubes by using compressive testing machine (UTM machine).

(b) Tensile Strength Test:

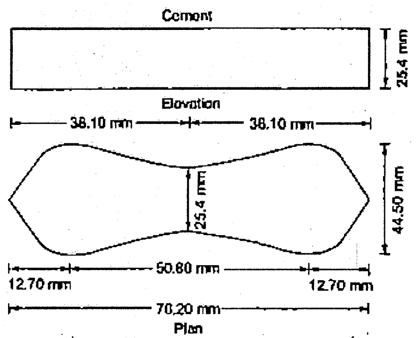


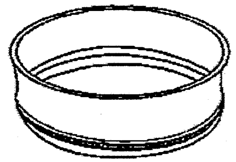
Fig. Standard briquette

- The tensile strength of cement may be obtained by Briquette test.
- A mixture of cement and sand is gauged in the proportion of 1:3 by weight.
- The percentage of water to be used is calculated by the formula $\left(\frac{P}{5}+2.5\right)$% where *P* is percentage of water required to produce a paste of standard consistency.
- The mix is filled in the briquette moulds and the surface of the mould is finished with the blade of a trowel.
- Briquette mould is then kept for 24 hours at a temperature of 27° ± 2°C and in an atmosphere having 90% humidity.
- The briquettes ($6.45\ cm^2$) are then kept in clean water and are taken out before testing.
- Six briquettes are tested and average tensile strength is calculated.
- Load is applied steadily and uniformly, starting from zero and increasing at the rate of 0.7 N/mm^2 in 12 seconds.
- OPC should have a tensile strength of not less than 2 MPa and 2.5 MPa after 3 and 7 days respectively.
- Generally tensile strength is 10-15% of compressive strength.
- Load applied steadily or uniformly from 0 to 0.7 N/mm^2 in 12 second.

1.7.7 Fineness Test

- Fineness is the measure of the size of the cement particles in terms of specific surface (i.e. surface area per unit mass).
- The rate of hydration and hydrolysis and the subsequent setting of cement depends upon its fineness of particles.
- The rate of gain of strength is rapid for finer cement, though the final strength is not affected by fineness.
- Fineness of cement is measured in terms of its specific surface.
- There are three methods for testing fineness viz.
  (i) Sieve method or particle size distribution method
  (ii) Air permeability method (Nurse and Blaine's method)
  (iii) Sedimentation method or Wagner's turbidimeter method

(a) Sieve Method:



- 100 gm of cement sample is taken and air set lumps, if any, in the sample are broken with fingers.
- The sample is placed on a 90 micron sieve and continuously sieved for 15 minutes.
- The residue should not exceed the limits specified below:

S.No.	Type of cement	% Residue by weight
(i)	Ordinary Portland cement	10
(ii)	Rapid hardening cement	5
(iii)	Portland pozzolana cement	5

(b) Air Permeability Method:

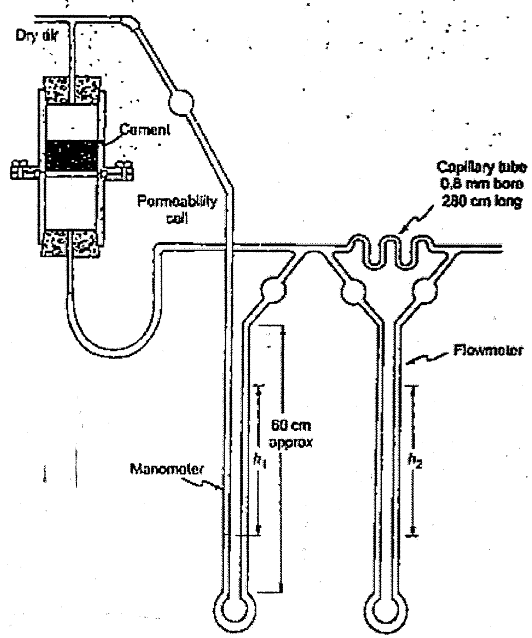


Fig. Permeability apparatus with manometer and flow meter.

- Fineness of cement is represented by specific surface i.e. total surface area in cm^2 per gram of cement.
- Fineness can be estimated either by using Lea and Nurse air permeability apparatus or by using Blaine's air permeability apparatus.
- To determine the fineness, a cement sample of 2 cm height is placed on a perforated plate (size of perforations is 40 μ) and air pressure is applied.
- The manometer is connected to the top of the permeability cell and the air is turned on.
- The lower end of the permeability cell is then slowly connected to the other end of the manometer.
- The rate of flow is so adjusted that the flowmeter shows a pressure difference (h_2) of 30-50 cm.
- The reading in manometer (h_1) is recorded.
- The process is repeated till the ratio $\frac{h_1}{h_2}$ attains a constant value.
- The specific surface is given by the expression

$$S = \frac{14}{d(1-\psi)}\sqrt{\frac{A\psi^3}{KL}}\sqrt{\frac{h_1}{h_2}}$$

where L is thickness of cement layer, A is area of cement layer, d is density of cement, ψ is porosity of cement (i.e. 0.475), h_2 is flowmeter reading, h_1 is manometer reading, K is flow meter constant

(c) Wagner Turbidimeter Test:

- The cement is dispersed uniformly in a rectangular glass tank filled with kerosene.
- Parallel light rays are passed through the solution which strike the sensitive plate of a photoelectric cell.
- The turbidity of the solution at a given instant is measured by taking readings of the current generated by the cell.
- By recording the readings at regular intervals while particles are falling in the solution, it is possible to secure information regarding the grading in surface area and in size of particle.
- Readings are expressed in cm^2/gm.

1.7.8 Heat of Hydration Test

- Heat is evolved during hydration of cement, the amount being dependent on the relative quantities of clinker compounds.
- The apparatus used to determine the heat of hydration of cement is known as calorimeter
- 60 gm of cement and 24 ml of distilled water are mixed for 4 minutes at a temperature between 15°-25°C.
- Three specimen glass vials 100 mm x 20 mm are filled with this mixture, corked and sealed with wax.
- The vials are then stored with mixture in a vertical position at 27° ± 2°C.
- The heat of hydration is obtained by subtracting the respective heat of solution of hydrated cement from the heat of solution of unhydrated cement calculated nearest to 0.1 calorie.
- The heat of solution of hydrated cement is calculated by using calorimeter.
- The heat of hydration for low heat Portland cement should not be more than 66 and 75 cal/gm for 7 and 28 days respectively.

1.7.9 Specific Gravity Test

- The specific gravity of cement is obtained by using Le Chatelier's flask.
- Long seasoning is the chief cause for low specific gravity in an unadulterated cement.
- The flask is filled either with kerosene free of water or naphtha having a specific gravity not less than 0.7313 to a point on the stem between zero and 1 ml mark.
- The flask is then immersed in a constant temperature water bath and the reading is recorded.
- A weighed quantity of cement is then introduced in small amounts at the same temperature as that of the liquid.
- After introducing all the cement, the stopper is placed in the flask and the flask is rolled in an inclined position, or gently whirled in a horizontal circle so as to free the cement from air until no further air bubbles rise to the surface of liquid.
- The flask is again immersed in water bath and the final reading is recorded.
- The difference between the first and the final reading represents the volume of liquid displaced by the weight of cement used in the test.

$$\text{Specific gravity} = \frac{\text{Weight of cement (in gms)}}{\text{Weight of displaced volume of liquid (in m}l\text{)}}$$

- The specific gravity of Portland cement is generally about 3.15.
- Specific gravity is not an indication of quality of cement. It is used in calculation of mix proportions.

Table

Type of Cement	Fineness	Soundness By		Setting Time		Compressive Strength			
	(m^2/kg) Min	Le chatelier (mm) Max.	Autoclave (%) Max.	Initial (mts) min.	Final (mts) max.	1 Days min MPa	3 Days min MPa	7 Days min MPa	28 Days min MPa
1. 33 Grade OPC (IS269–1989)	225	10	0.8	30	600	NS	16	22	33
2. 43 Grade OPC (IS 8112–1989)	225	10	0.8	30	600	NS	23	33	43
3. 53 Grade OPC (IS 12269–1987)	225	10	0.8	30	600	NS	27	37	53
4 SRC (IS 12330–1988)	225	10	0.8	30	600	NS	10	16	33
5. PPC (IS 1489–1991) Part I	300	10	0.8	30	600	NS	16	22	33
6. Rapid Hardening (IS 8041–1990)	325	10	0.8	30	600	16	27	NS	NS
7. Slag cement (IS 445–1989)	225	10	0.8	30	600	NS	16	22	33
8 High Alumina Cement (IS 6452–1989)	225	5	NS	30	600	30	35	NS	NS
9. Low Heat Cement (IS 6909–1990)	400	5	NS	30	600	NS	15	22	30
10. Low Heat Cement (IS 12600–1989)	320	10	0.8	60	600	NS	10	16	35
11. Masonary Cement (Is 3450–1988)	-	10	1	90	1440	NS	NS	2.5	5
12. IRT-T-40	370	5	0.8	60	600	NS	NS	37.5	NS

Objective Brain Teasers

Q.1 The main ingredients of Portland cement are
(a) line and silica
(b) line and alumina
(c) silica and alumina
(d) line and iron

Q.2 The constituent of cement which is responsible for all the undesirable properties of cement is
(a) dicalcium silicate
(b) tricalcium silicate
(c) tricalcium aluminate
(d) tetra calcium alumino ferrite

Q.3 Le Chatelier's device is used for determining the
(a) setting time of cement
(b) soundness of cement
(c) tensile strength of cement
(d) compressive strength of cement

Q.4 Addition of pozzolana to ordinary Portland cement increase
(a) bleeding
(b) shrinkage
(c) permeability
(d) heat of hydration

Q.5 Proper amount of entrained air in concrete results in
1. better workability
2. better resistance of freezing and thawing
3. lesser workability
4. less resistance to freezing and thawing

The correct answer is
(a) 1 and 2 (b) 1 and 4
(c) 2 and 3 (d) 3 and 4

Q.6 The most commonly used retarder in cement is
(a) gypsum
(b) calcium chloride
(c) calcium carbonate
(d) none of the above

Q.7 The most common admixture which is used to accelerate the initial set of concrete is
(a) gypsum
(b) calcium chloride
(c) calcium carbonate
(d) none of these

Q.8 According to IS specifications, the compressive strength of ordinary Portland cement after three days should not be less than
(a) 7 MPa (b) 11.5 MPa
(c) 26 MPa (d) 21 MPa

Q.9 Increase in fineness of cement
(a) reduces the rate of strength development and leads to higher shrinkage
(b) increases the rate of strength development and reduces the rate of deterioration
(c) decreases the rate of strength development and increases the bleeding of cement
(d) increases the rate of strength development and leads to higher shrinkage

Q.10 The initial setting time for ordinary Portland cement as per IS specifications should not be less than
(a) 10 minutes (b) 30 minutes
(c) 60 minutes (d) 600 minutes

Answers

1. (a)	2. (c)	3. (b)	4. (b)	5. (a)
6. (a)	7. (b)	8. (c)	9. (d)	10. (b)