OPSC 2019

Odisha Public Service Commission

Assistant Engineer Examination

Civil Engineering

Building Materials

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**

MADE EASY Publications

Building Materials

Contents

CHAPTER 1

Cement

1.1 Introduction

- Cement is an extremely fine material having adhesive and cohesive properties which provides a binding medium for the discrete ingredients.
- Cement is a product obtained by pulverizing clinker formed by calcinating raw-materials primarily 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 hardens and bind aggregates (fine coarse) together to form a hard durable mass called concrete.
- Cements used in construction industry can be classified as hydraulic and non-hydraulic.
- Hydraulic cement set and harden extremely fast in presence of water (Due to the chemical action between cement and water known as hydration) and results in water resistance product which is stable. This allows setting in wet condition or underwater and further protects the hardened material from chemical attack. e.g.: (Portland cement).
- Non-hydraulic cements are derived from calcination of gypsum or limestone because their products of hydration are not resistant to water. However, the addition of pozzolanic materials can render the gypsum and make cement hydraulic. Thus, it will not set in wet condition or underwater, rather it sets as it dries and reacts with carbon-dioxide in the air. It can be attacked by some aggressive chemicals after setting. e.g.: Plaster of Paris.
- The cement experiences the exothermic chemical reactions when comes in contact with water.
- The cement is assumed to have a specific gravity of 3.15.
- Standard density of cement is 1440 kg/m^3 and 1 bag of cement is of 50 kg, thus volume would be 50/1440 = 0.0347 m^3.

  Hence, volume of 1 bag of cement can be approximated as 0.035 m^3 or 35 litres.
- Cement can be manufactured either from natural cement stones or artificially by using calcareous and argillaceous materials.

Argillaceous	Calcareous
• Shale and clay • Blast furnace slag • Slate	• Cement rock • Limestone • Chalk • Marine shells • Marl

1.2 Cement and Lime

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

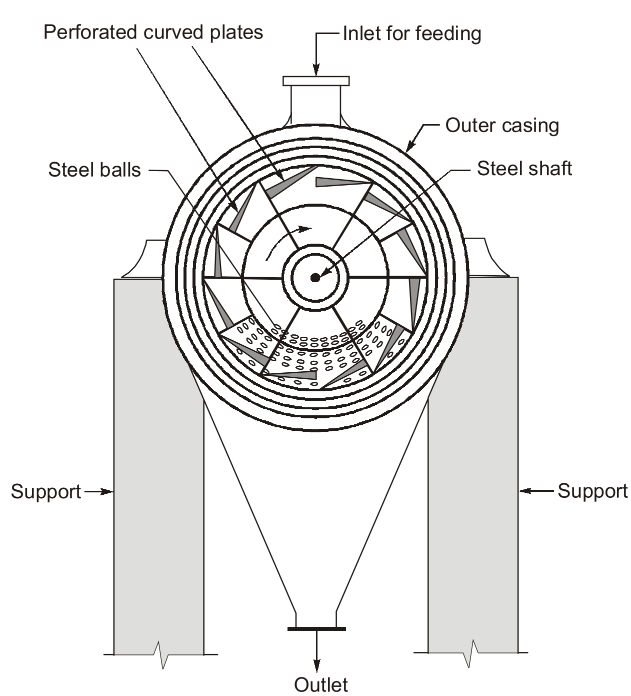
1. The cement is used for the gain of early strength whereas lime gains the strength slowly.
2. The cement and lime color are different.
3. The cement and lime both is a binding material having good ultimate strength but lime experiences less early strength as compare to cement.

1.3 Manufacture of Cement

- The manufacturing of cement was first started in England by the scientist named Joseph Aspdin.
- The first time manufacturing of cement is named as Ordinary Portland Cement (OPC) because when the cement comes in contact with water it becomes a hard mass after a certain period and this hard mass resembles the stone found in portland area of England.
- The India is 2^{nd} largest manufacturing hub after China.
- The cement is manufactured by integrating the calcareous component and argillaceous component in ratio 3 : 1.
- The calcareous components 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.
- Cement can be manufactured either by dry process or wet process.

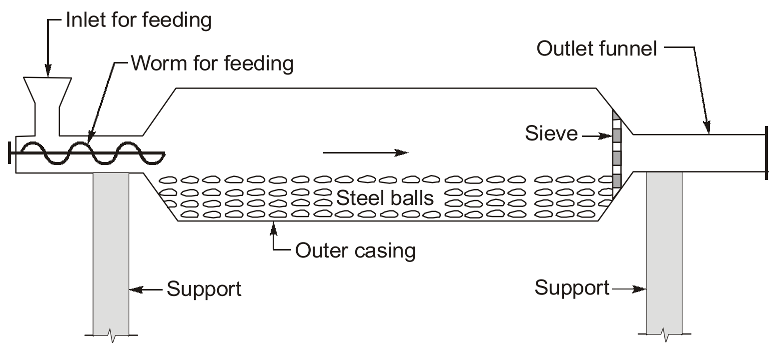
1.3.1 Dry Process

Step (i): The material is gathered from quarry with the help of dumper to manufacturing plant. The material gathered is having content of limestone and clay which is calcareous component and argillaceous component respectively. The material gathered is about more than 80 mm size.



Vertical Section of a Ball Mill

Step (ii): The collected material is fed into heavy crusher where the size of the material get reduced to 60 mm from 80 mm and later this size material is fed into light crusher (Tubemill/Ballmill) where the size reduced to 40-60 mm finally it is stored in the tank.



Longitudinal Section of a Tube Mill

Step (iii): Now, the grinding material called raw mix is fed into preheater (heater before rotary kiln), the temperature is gradually increased upto 500°C due to this increase in temperature the raw mix get fraction into smaller size nearly (25 mm).

Benefits of Preheaters:

(a) It makes the process fast.

(b) Fuel consumption is reduced because the burning time of rotary kiln is get reduced.

Now, this raw mix is fed into rotary kiln where the temperature is 800-1000°C, 1000-1200°C, 1200°-1500°C. In three separate zones respectively. The product obtained is of size 8 to 10 mm from rotary kiln is called clinker.

Rotary Kiln

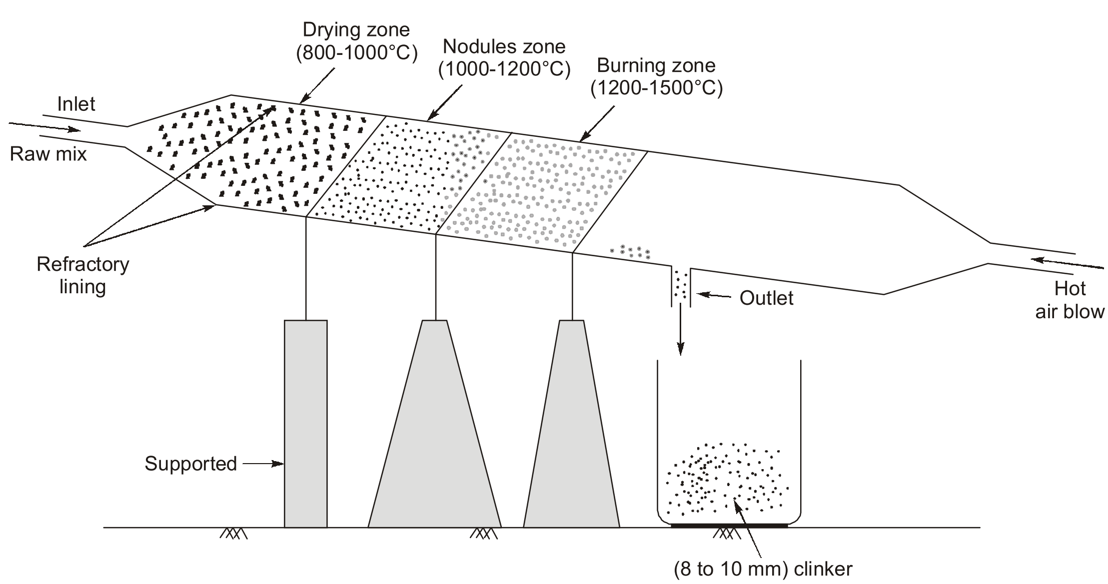
Dimensions:

Diameter = 3 m

Length = 100 m

Revolutions = 3 rounds in 1 minute

Gradient 1 in 25 to 1 in 30.



Zone-1 (Drying zone): In this zone the raw mix, is fractioned into more smaller size. In this zone if there is some water or moisture exist in raw mix then it is also evaporated.

Zone-2 (Nodule zone): In this zone, the major breakdown of raw mix occur. In this zone the calcination of limestone takes place $\underset{\text{(Limestone)}}{CaCO_3} \xrightarrow{\text{Superheat}} \underset{\text{(Lime)}}{CaO} + CO_2 \uparrow$.

Zone-3 (Burning zone): Now, the raw mix which is also called nodules, is sloped down and the major chemical reaction between ingredient of clinker occurs i.e. lime, silica, alumina, iron oxides.

$$\left.\begin{aligned} &2\,CaO + SiO_2 \rightarrow Ca_2SiO_4\ (C_2S) \\ &3\,CaO + SiO_2 \rightarrow Ca_3SiO_5\ (C_3S) \\ &3\,CaO + Al_2O_3 \rightarrow Ca_3Al_2O_6\ (C_3A) \\ &4\,CaO + Al_2O_3 \rightarrow Fe_2O_3\ (C_4AF) \end{aligned}\right\} \text{Bouge's compounds}$$

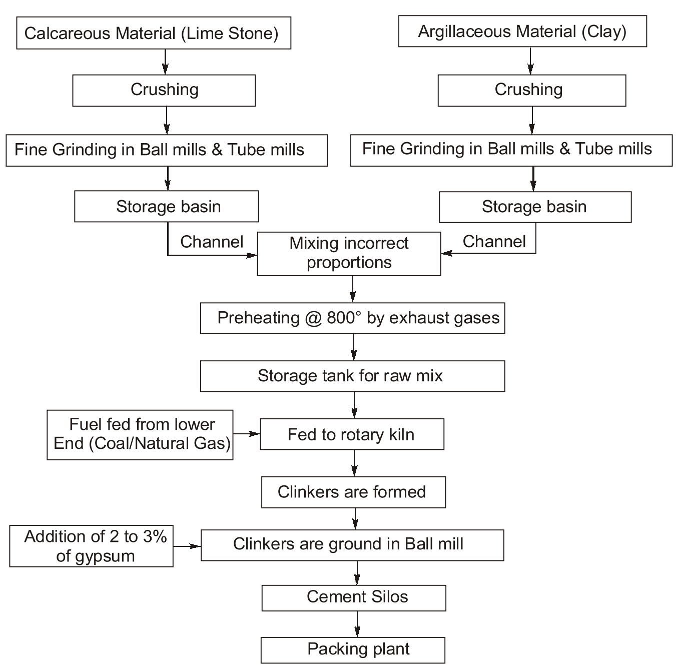
Now, from this rotary kiln the product obtained is called clinker which is composed of major and minor compounds.

NOTE: The clinker obtained has high efficiency to react with water and set immediately (flash set) to prevent this immediately setting of clinker in presence of water is done by adding gypsum in a tubemill.

(v) Now, the clinker is cooled upto temperature of 100°C, after colling it is fed into tubemill where the gypsum is also added to it, the fine grinded powder having gray colour is obtained which is called cement.

(vi) It is packed in 50 kg bag having ±5% volume capacity of 0.035 m^3.

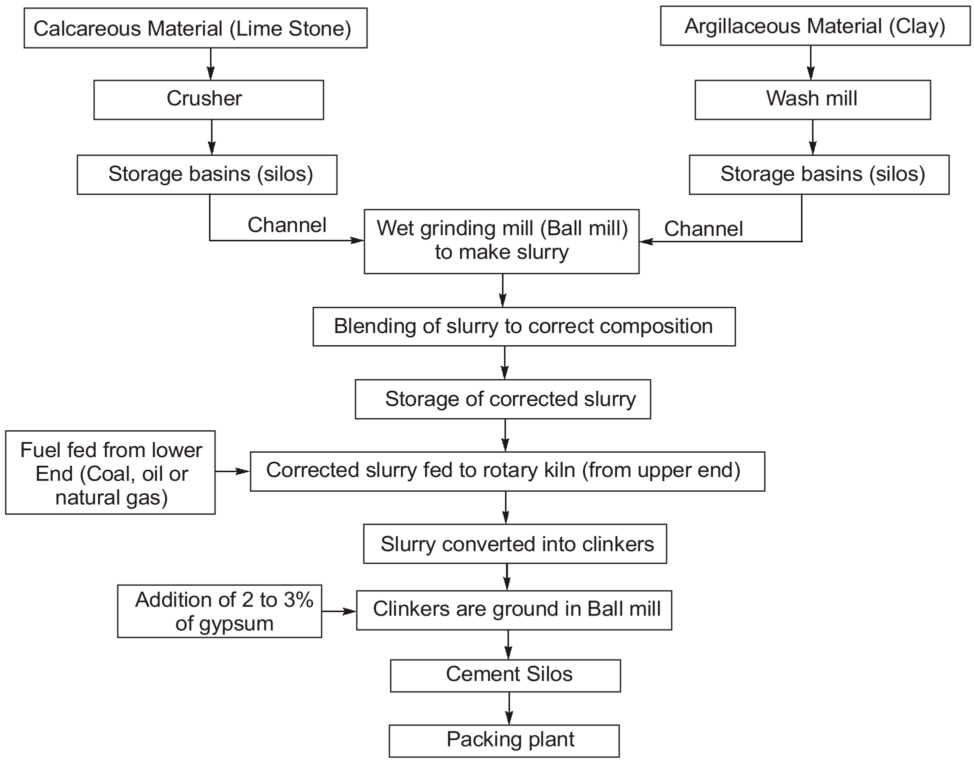
(vii) Now, after packing it is transported to dealers.



Flow diagram of dry process

1.3.2 Wet Process

In a wet process the heavier crushed material is made wet in storage tank before feeding into tubemill. In wet process, the preheater is not used, the mix obtained from tubemill is directly fed into rotary kiln.



Flow diagram of wet process

Disadvantages

(i) The process time is long.

(ii) The fuel consumption is more.

1.4 Chemical Composition of Cement

Oxide	Composition (%)	Average
Lime CaO	60 - 65	63
Silica, SiO_2	17 - 25	20
Alumina, Al_2O_3	3 - 8	6
Iron oxide, Fe_2O_3	0.5 - 6	3
Magnesia, MgP	0.5 - 4	2
Soda/or potash ($Na_2O + K_2O$)	0.5 - 1	1
Sulphur tri-oxide	1 - 2	1.5

- The relative proportional of three oxide compositions are responsible for influencing the various properties of cement, like lime, silica and alumina.
- An increase in lime content beyond a certain value makes it difficult to combine completely with other compounds.
- Consequently, free time 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.

1. Lime (CaO)

If lime is provided in excess then the cement becomes unsound and if it is in deficiency then the strength is reduced therefore chances of quick setting will be enhanced.

2. Silica (SiO_2)

It imparts strength to the cement due to the formation of di-calcium and tri-calcium silicates. If it is in excess then the strength of the cement would enhanced therefore setting time gets prolonged, hence it prevents quick setting.

3. Alumina (Al_2O_3)

It imparts quick setting property of cement. If it is in excess then the strength of cement is reduced and the chances of rapid hardening would be increased. It acts as a flux and it lower's the clinker temperature.

4. Calcium Sulphate ($CaSO_4$)

It is a retarder (admixture). If it is in excess then it slowdown the quick setting which dominates to increase the strength. It is a gypsum form.

5. Iron Oxide (Fe_2O_3)

It imparts colour, hardness, and strength to the cement. If it is in excess, then it imparts more coloured to the cement (grey).

6. Magnesia (Mgo)

It imparts hardness and colour (yellow) to the cement, if it is in small quantity, and if it is in excess then it imparts unsoundness to the cement.

7. Sulphur (S)

If it is in reference quantity then it imparts strength to the cement and it it is in excess then the unsoundness is increased.

8. Alkalies (Soda and Potash) ($Na_2O + K_2O$)

The most of the alkalies present in raw materials are carried away by the flue gases heating and the cement contents only a small amount of alkalies. If they are in excess in cement then they cause a number of troubles such as alkali-aggregate reaction, efflorescence and staining when used in concrete, brick work or masonary mortar.

1.5 Basic Properties of Bougie Compounds

The principle mineral compounds in portland cement	Formula	Name	Symbol	Percentage
1. Tri-calcium silicate	$3CaOSiO_2$	Alite	C_3S	30 - 50%
2. Di-calcium silicate	$2CaOSiO_2$	Belite	C_2S	20 - 45%
3. Tri-calcium alluminate	$3CaOAl_2O_3$	Celite	C_3A	8 - 12%
4. Tetra-calcium alumino ferrite	$4CaOAl_2O_3$ Fe_2O_3	Felite	C_4AF	6 - 10%

1. Tri-calcium Silicate (C_3S)

It produces faster rate of reaction with greater heat evolution, it imparts early strength to the cement and also contribute good for ultimate strength. If it is in excess then rapid hardening enhances.

2. Di-calcium Silicate (C_2S)

It hydrates slowly and imparts ultimate strength much. The C_2S has less heat of hydration therefore it is resistant against chemical attack.

3. Tri-calcium Aluminate (C_3A)

It imparts fast reaction with water and it produces very high heat therefor it imparts more towards rapid hardening.

If C_3A would be more then immediate setting (flash set) would be enhanced to prevent this flash setting gypsum is added to it during manufacturing.

4. Tetracalcium Alumino Ferite (C_4AF)

It also reacts with water at faster rate and evolves heat by greater extent but it is more stable then C_3A because if produces less heat compared to C_3A.

NOTE

Decreasing order of ultimate: ($C_2S > C_3S > C_3A > C_4AF$)
Decreasing order of quickest reaction with water: ($C_3A > C_4AF > C_3S > C_2S$)

- 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. $C_4AF > C_3A > C_3S > C_2S$

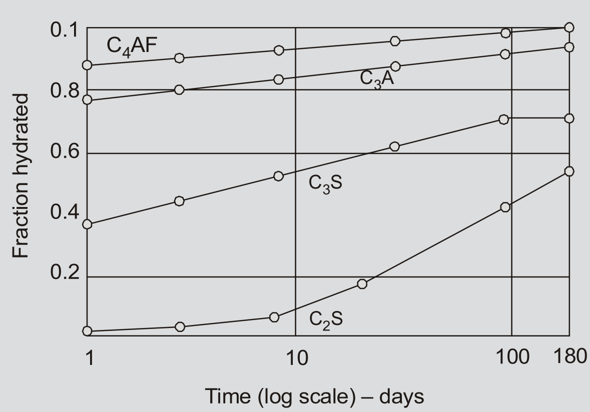


***Fig.** Rate of Hydration of Pure Compounds*

- 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	886.16	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.

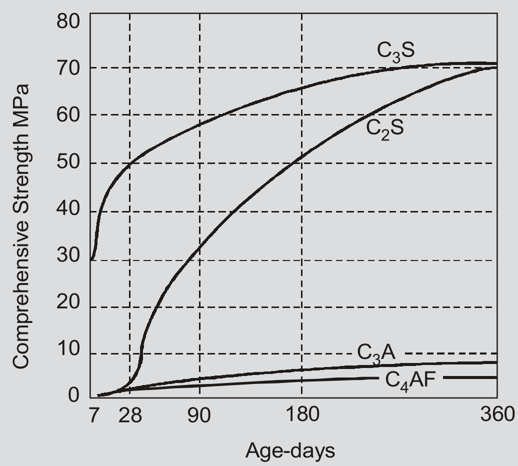


***Fig.** Development of Strength of Pure Compounds*

1.6 Hydration of Cement

- The chemical reaction of cement with water is referred as hydration of cement.
- The reaction of cement and water is exothermic reaction i.e. heat is liberated in a considerable quantity and this liberated heat is called heat of hydration.
- The water added to the cement will leads to evolution of heat, the C_3S and C_2S reacts with water during hydration to form a calcium silicate hydrate along with $Ca(OH)_2$.
- The calcium silicate hydrate is responsible for good properties of cement concrete. The calcium silicate hydrate is having binding property whereas the $Ca(OH)_2$ is not a desirable product in a cement concrete because it is responsible for lack of durability of concrete.
- The $Ca(OH)_2$ also reacts with sulphur present in water or soil to form $CaSO_4$. Which further reacts with C_3A and C_4AF to cause a deterioration of concrete this effect is called sulphate attack.

$$C_3S + \text{Water} \rightarrow \text{C-S-HGel} + Ca(OH)_2$$

$$C_2S + \text{Water} \rightarrow \underbrace{\text{C-S-H Gel}}_{\text{Binding proprty}} + \underbrace{Ca(OH)_2}_{\text{Durability}}$$

$$Ca(OH)_2 + \text{Sulphur} \rightarrow CaSO_4 + C_3A$$

$$\underbrace{CaSO_4 + C_4AF}$$

↓

Product (Salty nature)

↓

Deterioration of concrete

↓

Durability decreases

- To reduce sulphate attack:
  1. Sulphur content in water (↓es)
  2. C_3A and C_4AF (↓es)

NOTE

The total amount of water required for complete chemical reaction between cement and water is 38%. If the gel pores/voids in cement exist where 15% of water is required to fill the voids and gel pores and this percentage is taken by weight.

1.7 Types of Cement

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

1.7.1 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:
- 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.

1.7.2 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.

1.7.3 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.

1.7.4 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.

1.7.5 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.

1.7.6 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)

1.7.7 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.

1.7.8 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/mm^2
  7 Day ± 2 hr = 16 N/mm^2
  28 Day ± 4 hr = 33 N/mm^2
- 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.

1.7.9 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) $Na_3 AlF_6$ 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.

1.7.10 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/mm^2 and that after 3 days is about 50 N/mm^2.

- 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.

1.7.11 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.

1.7.12 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 retentively.
- 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 to lime mortar and discards all the non ideal properties of cement mortar.

1.7.13 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/mm^2
  7 Day ± 2 hr = 22 N/mm^2
  28 Day ± 4 hr = 30 N/mm^2

- 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.

1.7.14 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.

1.7.15 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**.

1.8 Testing of Cement

1.8.1 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.