CIVIL ENGINEERING

Construction Materials

Comprehensive Theory
with Solved Examples *and* Practice Questions

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CHAPTER

1

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 pirmarily consisting of Lime (CaO), Silica (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, i.e. finer the grains of the cement more is the strength of cement.
- Joseph Aspdin manufactured cement and called it Portland cement because when it is gets hardened, it produces a material resembling stone from the quarries near Portland in England.
- 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 color of cement and lime are different.
3. The cement and lime both acts as binding material having good ultimate strength but lime experiences less early strength as compare to cement.
4. The cement is having good heat of hydration due to which it sets early as compared to other binding material like lime.

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.
- The manufacturing of cement can be done through the following two processes i.e. dry and wet processes.

(a) Wet process:
- It is the oldest method of manufacturing cement which is now-a-days obsoleted.
- It is a costly method because it requires higher degree of fuel consumption, power consumption etc.

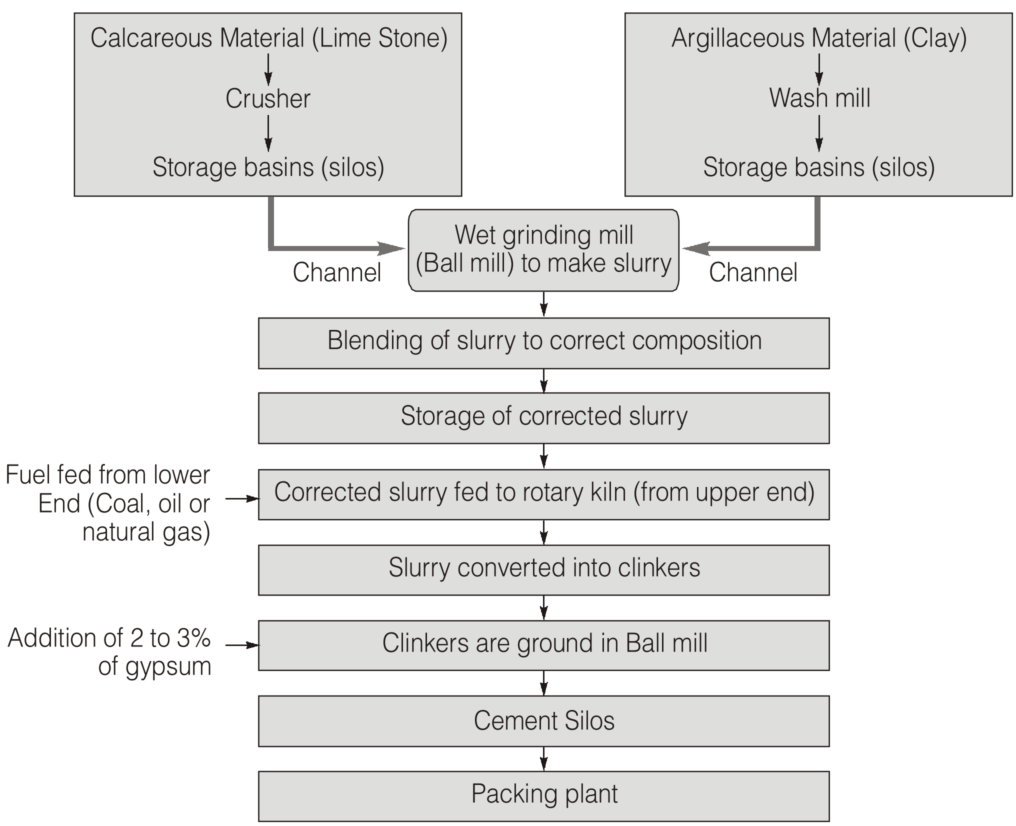


Fig. *Flow diagram of wet process*

(b) Dry process:
- It is a new method of manufacturing cement which is trending now-a-days.
- The fuel consumption and power consumption has been reduced to a greater extent by modifying the wet process.

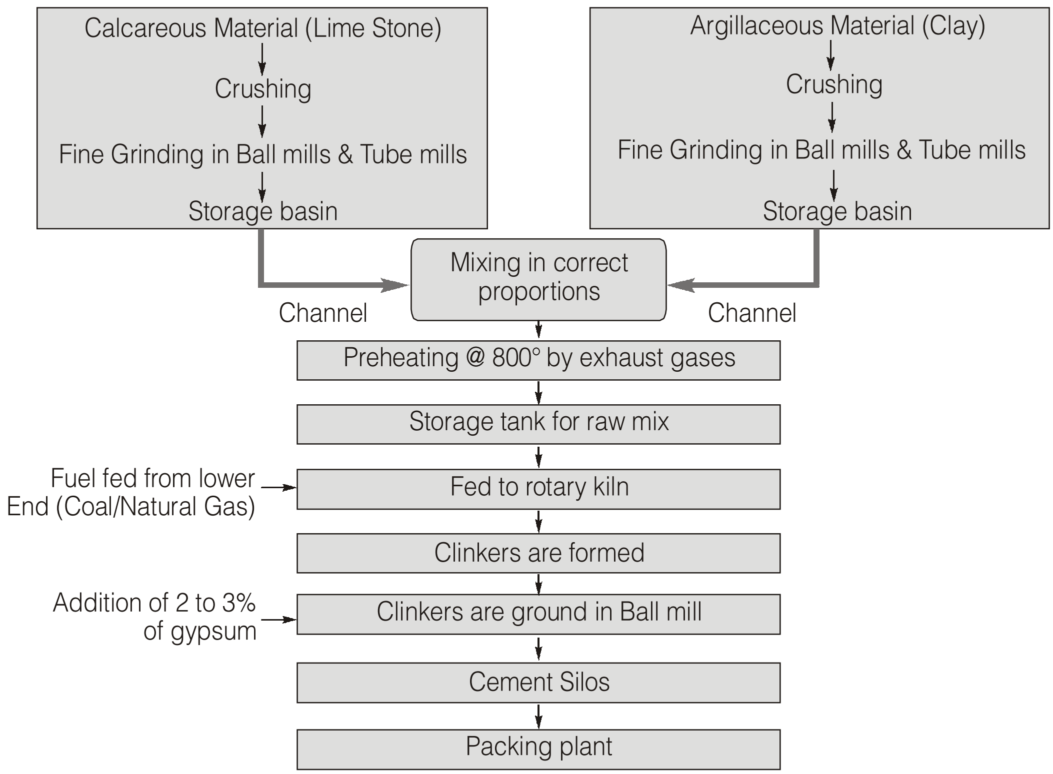


Fig. *Flow diagram of dry process*

1.3.1 Dry Process

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

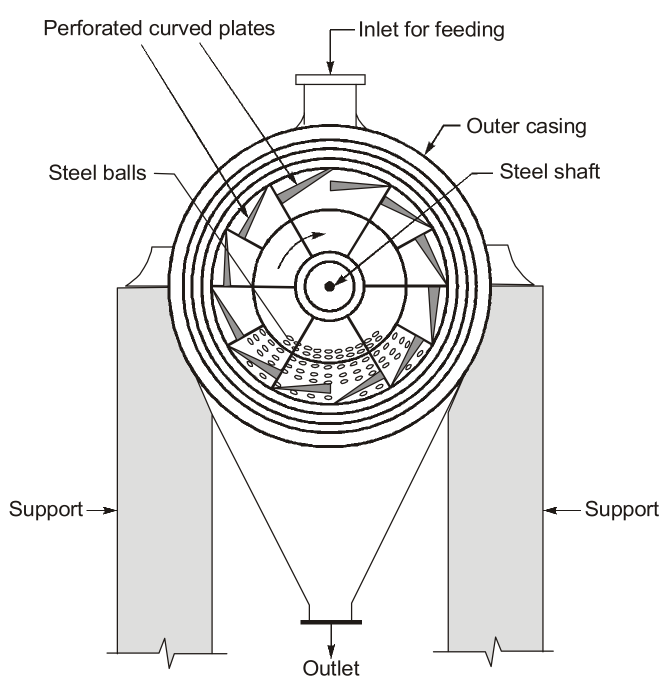


Fig. Vertical Section of a Ball Mill

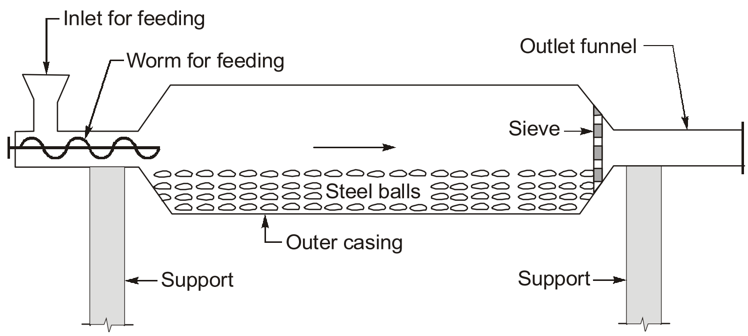


Fig. Longitudinal Section of a Tube Mill

- 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 is checked for content of $CaCO_3$, Lime, Alumina, Silica, Fe_2O_3. Any component found short in quarried material is added separately. Example, If Silica is less then, crushed sandstone is added separately 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".

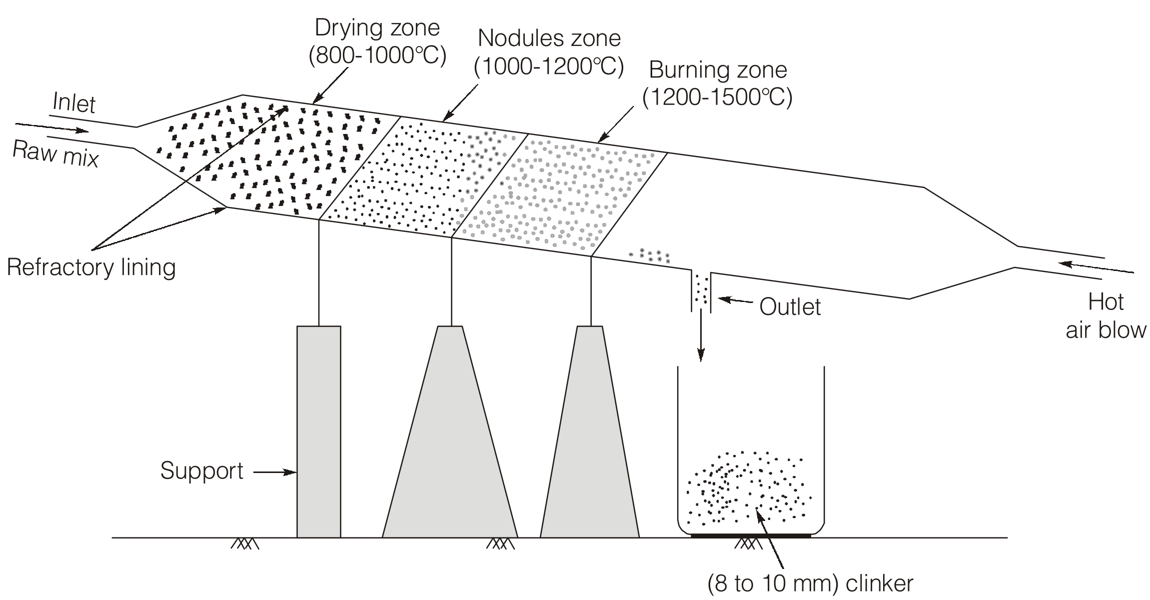


Fig. *Rotary Kiln for wet process*

- The rotary kiln in dry process, doesnot have the drying zone and hence, is shorter in length than compared to kiln of wet process. For rotary kiln, generally,

  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.

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

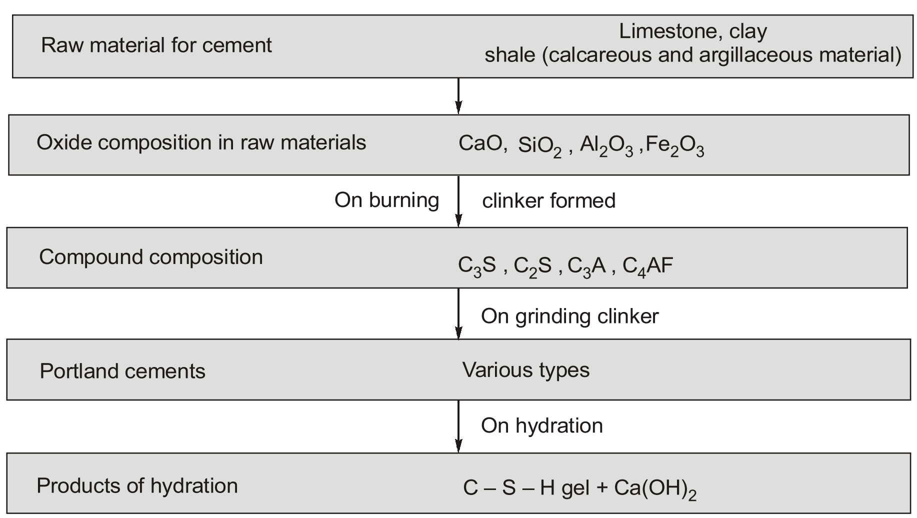
$$3CaO + SiO_2 \longrightarrow Ca_3SiO_5 = C_3S \text{ (Tricalcium Silicate)}$$

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

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

The product obtained from rotary kiln is called clinker which is composed of major compound (Bougue's Compound) and Minor Compound 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 to reduce quick setting.
- The retarder is admixture which delays the setting time of the cement clinker.
- The final binding material is C – S – H gel i.e. Calcium silicate hydrate gel which is formed when the hydration of cement takes place.



NOTE

Wet process is advantageous than dry process due to following reasons:
- Low cost of excavating and grinding raw material.
- Accurate control of composition and homogeneity of the slurry.
- Economic utilization of fuel through the elimination of separated drying operations.

But, on the other hand, wet process having longer Kiln, due to which cost is more and are less responsive to variable clinker demand are the major disadvantage of this process and hence become obsolete now-a-days.

1.3.2 Composition of Cement Clinker (Bougue's compound)

- The major compounds that are formed when cement reacts chemically with water are shown in table.

Table: Principle compounds in portland cement

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 such as Soda (Na_2O) and Potash (K_2O) are also formed. These two minor compounds are chiefly responsible for **Efflorescence** in cement concrete and cement mortar.

> **NOTE** 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 that of **90 percent in 1 year**.
- The strength in a cement is majorly depends upon the Bougue's compound. The properties of Portland cement varies significantly with the proportion of four Bougue's compounds.

(A) Tricalcium Silicate C_3S (30 to 50%)

- It enables the clinker to grind easily.
- It hydrates rapidly generating high heat and develop early hardness and strength.
- It increases the resistance to **freezing and thawing.**
- Increasing C_3S content beyond specific limit increases the heat of hydration and solubility of cement in water.
- 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 also contributes considerably upto 28 days strength gain.
- It is the compound which has maximum contribution in 28 days strength among all Bouge's compound and is responsible for gain of strength from 24 hours to 28 days, its own maximum contribution is upto 14 days.
- The heat of hydration is 500 J/g.

(B) 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 of cement**.
- It imparts **resistance to chemical attack**.
- Increasing C_2S content reduces the early strength, decreases the resistance to freezing and thawing at early ages and also 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 a stable cement with respect to durability of structure.
- The contribution of C_2S in strength gain 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/g.

(C) 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 (i.e. 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.
- It contributes in 24 hours strength after addition of water but it contribute lesser than other compounds.
- Increasing the C_3A content reduces the setting time and also weakness the resistance to subphate attack.
- It has heat of hydration 865 J/g.

NOTE
- Flash setting ocurs due to more C_3A content and lesser gypsum. After flash setting, remixing is not possible.
- False setting occurs due to ansyndrous form of gypsum. This gypsum have tendency to abosrb more H_2O, due to which it seems like setting has take place. By adding extra water and remixing, we can remove this flash setting.

(D) Tetra-calcium Aluminate Ferrite C_4AF (6 to 10%)

- It is also responsible for high heat of hydration as compared to C_2S and but less than C_3A.
- Its contribution in gain of strength is very less.
- It is having contribution within 24 hours of adding water to the cement.
- The heat of hydration 420 J/g.

NOTE

Development of strength of four Bougue's compounds of cement with age.

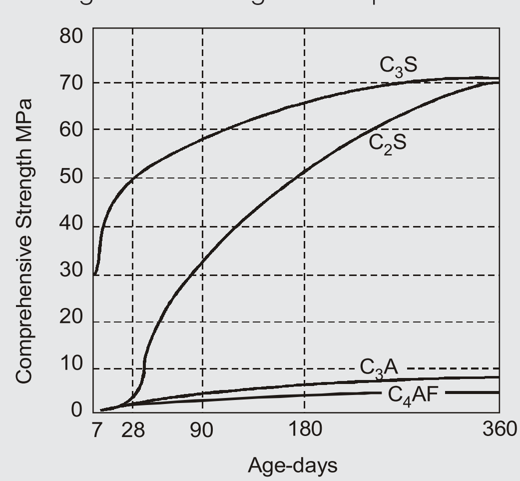


Fig. Development of Strength of Pure Compounds