

# CIVIL ENGINEERING

## Construction Materials



Comprehensive Theory  
*with Solved Examples and Practice Questions*





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## **Construction Materials**

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# Cement

## CHAPTER

# 1

## 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 primarily consisting of Lime ( $\text{CaO}$ ), Silica ( $\text{SiO}_2$ ), Alumina ( $\text{Al}_2\text{O}_3$ ) and Iron oxide ( $\text{Fe}_2\text{O}_3$ ).
- 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 assumed 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  $0.035 \text{ m}^3$ .

## 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 obsolete.
- It is a costly method because it requires higher degree of fuel consumption, power consumption etc.

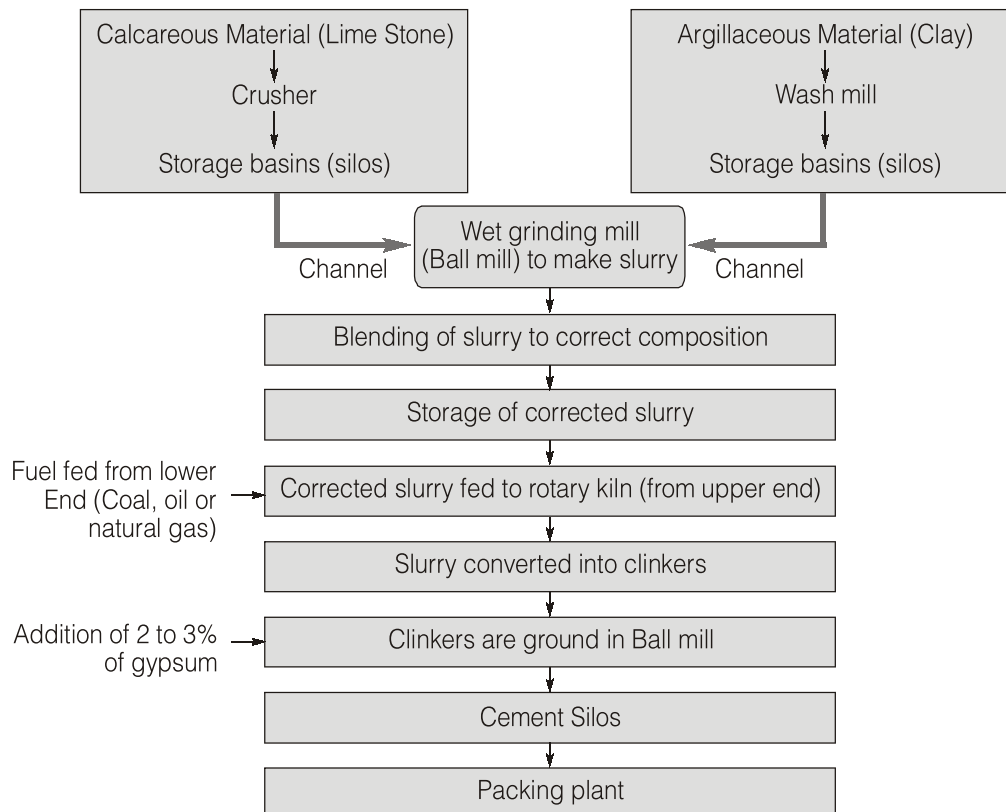


Fig. Flow diagram of wet process

#### (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.

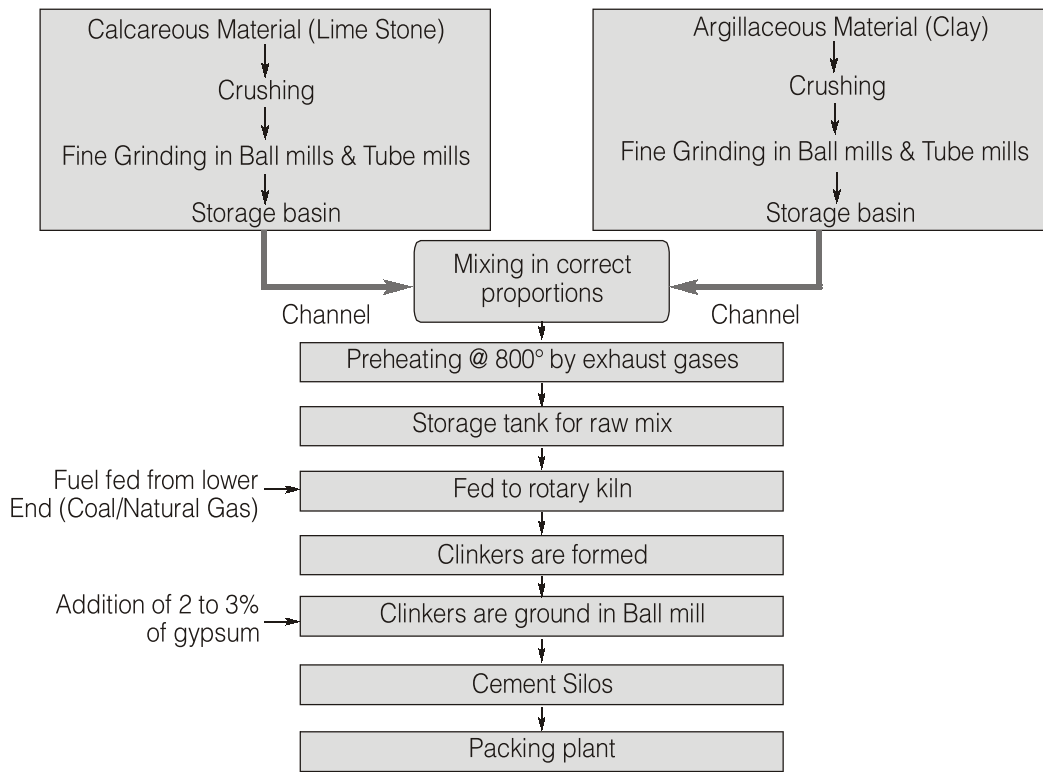


Fig. Flow diagram of dry process

### 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.

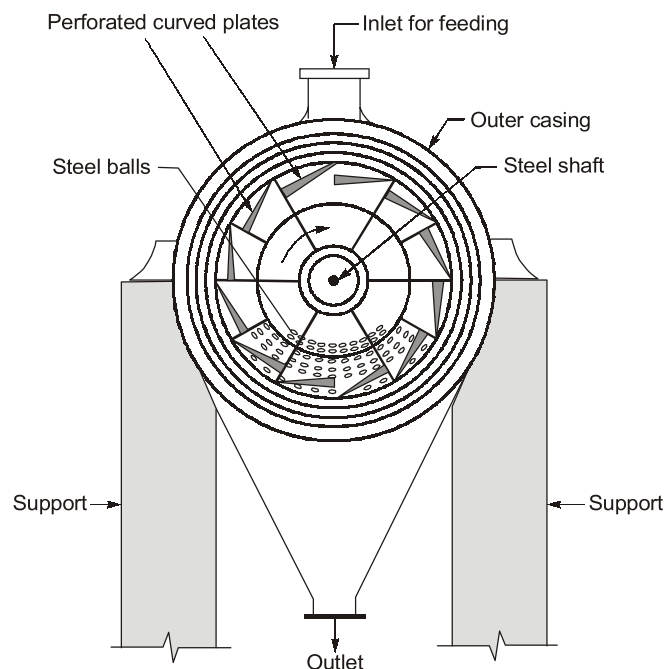


Fig. Vertical Section of a Ball Mill

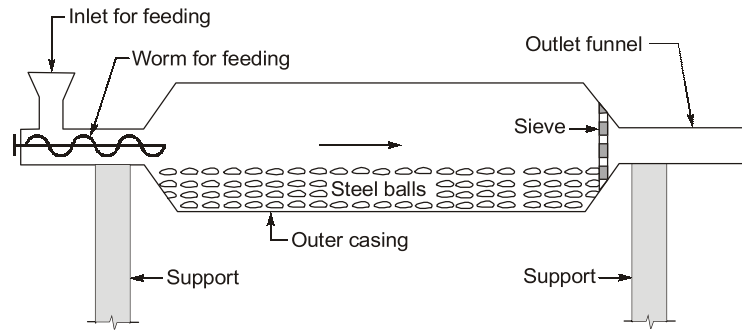


Fig. Longitudinal Section of a Tube Mill

- 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  $850^{\circ}\text{C}$  which reduces the burning time of raw mix in rotary kiln.



The crushed material is checked for content of  $\text{CaCO}_3$ , Lime, Alumina, Silica,  $\text{Fe}_2\text{O}_3$ . 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".

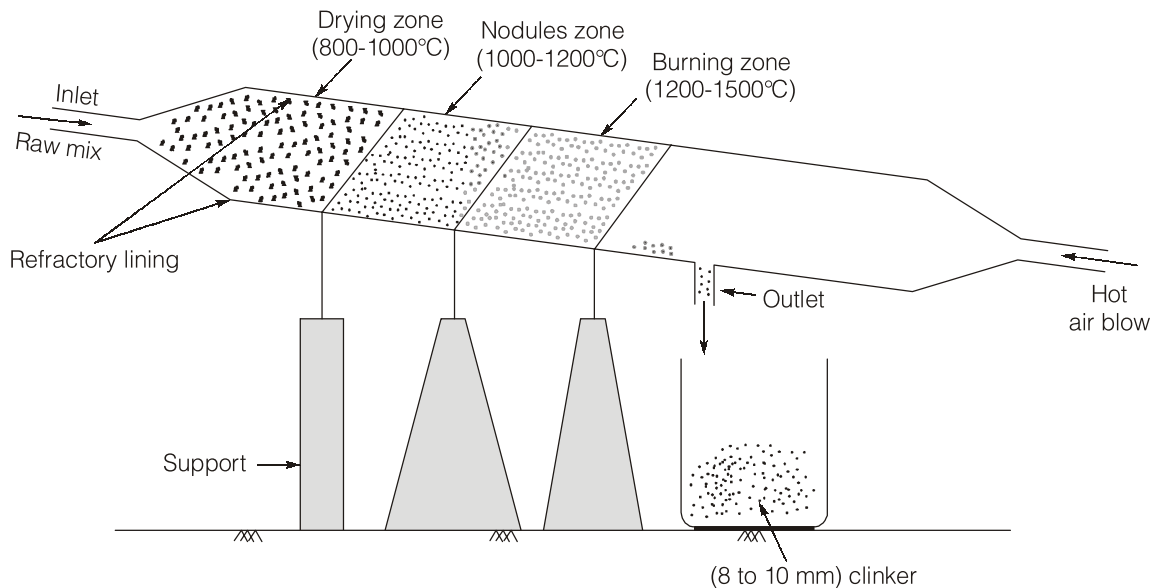


Fig. Rotary Kiln for wet process

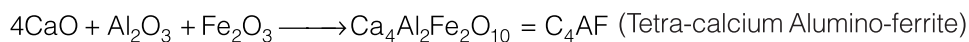
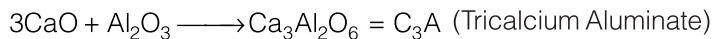
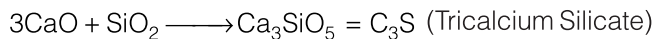
- The rotary kiln in dry process, doesnot have the drying zone and hence, is shorter in length than compared to kiln of wet process. For rotary kiln, generally,  
 Diameter = 2.50 to 3 metre                      Length = 90 to 120 metre  
 Volume  $\approx 706.3 \text{ m}^3$                                   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.



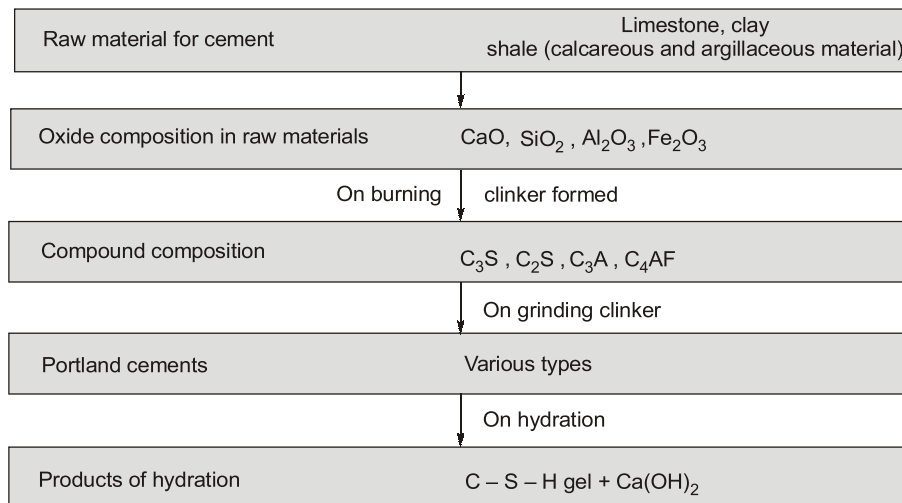
As the CO<sub>2</sub> is evaporated from the raw mix, the raw mix get converted into nodules.

- **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.



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.



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.

The principal mineral compounds in Portland cement	Formula	Name	Symbol	Percentage
1. Tricalcium silicate	$3\text{CaO} \cdot \text{SiO}_2$	Alite	$\text{C}_3\text{S}$	30-50%
2. Dicalcium silicate	$2\text{CaO} \cdot \text{SiO}_2$	Belite	$\text{C}_2\text{S}$	20-45%
3. Tricalcium aluminate	$3\text{CaO} \cdot \text{Al}_2\text{O}_3$	Celite	$\text{C}_3\text{A}$	8-12%
4. Tetracalcium aluminoferrite	$4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$	Felite	$\text{C}_4\text{AF}$	6-10%

- Besides major compounds, minor compounds such as Soda ( $\text{Na}_2\text{O}$ ) and Potash ( $\text{K}_2\text{O}$ ) are also formed. These two minor compounds are chiefly responsible for **Efflorescence** in cement concrete and cement mortar.



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 $\text{C}_3\text{S}$ (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  $\text{C}_3\text{S}$  content beyond specific limit increases the heat of hydration and solubility of cement in water.
- The hydration of  $\text{C}_3\text{S}$  is mainly responsible for 7 days strength and hardness.
- The  $\text{C}_3\text{S}$  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 Bougue'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 $\text{C}_2\text{S}$ (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  $\text{C}_2\text{S}$  content reduces the early strength, decreases the resistance to freezing and thawing at early ages and also decreases heat of hydration.
- At early days  $\text{C}_2\text{S}$  has little influence on strength and hardness, where after a year its contribution is same as  $\text{C}_3\text{S}$  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 sulphate attack.
- It has heat of hydration 865 J/g.



- Flash setting occurs due to more  $C_3A$  content and lesser gypsum. After flash setting, remixing is not possible.
- False setting occurs due to anhydrous form of gypsum. This gypsum have tendency to absorb 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.



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

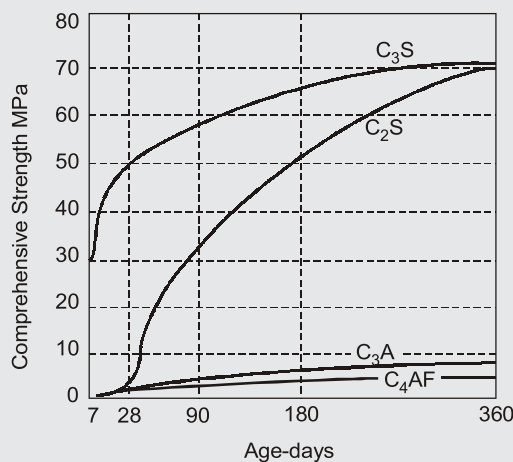


Fig. Development of Strength of Pure Compounds

- 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.

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

- 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.



**OBJECTIVE  
BRAIN TEASERS**

- Q.1** The main ingredients of Portland cement are  
(a) lime and silica (b) lime and alumina  
(c) silica and alumina (d) lime 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** Consider the following statements regarding high alumina cement :  
1. It allows more time for mixing and placing operations.  
2. It cannot withstand high temperatures.  
3. It is not affected by frost action.  
4. It is costly.  
Which of the above statements are CORRECT?  
(a) 1, 2 and 3 (b) 2, 3 and 4  
(c) 1, 3 and 4 (d) 1 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** Match **List-I** (Type of cement) with **List-II** (Properties) and select the correct answer using the codes given below the lists:

**List-I**

- A. High strength portland cement
- B. Super sulphate cement
- C. High alumina cement
- D. Rapid hardening portland cement

**List-II**

1. Should not be used with any admixture
2. Is extremely resistant to chemical attack
3. Gives a higher rate of heat development during hydration of cement
4. Has a higher content of tricalcium silicate

**Codes:**

- |     | A | B | C | D |
|-----|---|---|---|---|
| (a) | 3 | 2 | 1 | 4 |
| (b) | 4 | 1 | 2 | 3 |
| (c) | 3 | 1 | 2 | 4 |
| (d) | 4 | 2 | 1 | 3 |

**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

**Q.11** Which of the following is not correctly matched for the important constituents of cement?

- |     | Constituents                                 | Percentage |
|-----|--|------------|
| (a) | Lime (CaO)                                   | 60-67%     |
| (b) | Silica (SiO <sub>2</sub> )                   | 17-25%     |
| (c) | Alumina (Al <sub>2</sub> O <sub>3</sub> )    | 25-30%     |
| (d) | Iron oxide (Fe <sub>2</sub> O <sub>3</sub> ) | 0.5-6%     |

**Q.12 Assertion (A):** The most important limitation of the Le Chatelier test is that it detects unsoundness due to free lime only.

**Reason (R):** Le Chatelier method does not indicate the presence and after effect of the excess of magnesia.

- (a) Both A and R are true and R is the correct explanation of A.
- (b) Both A and R are true but R is not a correct explanation of A.
- (c) A is true but R is false.
- (d) A is false but R is true.

**Q.13** Match **List-I** (Ingredient of cement) with **List-II** (related function) and select the correct answer using the codes given below the lists:

- | <b>List-I</b>       | <b>List-II</b>   |
|---------------------|------------------|
| A. Silica           | 1. Quick setting |
| B. Alumina          | 2. Unsoundness   |
| C. Calcium sulphate | 3. Strength      |
| D. Sulphur          | 4. Retarder      |

**Codes:**

- |     | A | B | C | D |
|-----|---|---|---|---|
| (a) | 1 | 3 | 2 | 4 |
| (b) | 1 | 3 | 4 | 2 |
| (c) | 3 | 1 | 2 | 4 |
| (d) | 3 | 1 | 4 | 2 |

**Q.14** The raw material used to prepare sulphate resisting cement, when compared with OPC, will have

- (a) more quantity of Al<sub>2</sub>O<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub> both
- (b) same quantity of Fe<sub>2</sub>O<sub>3</sub> and more of Al<sub>2</sub>O<sub>3</sub>
- (c) same quantity of Al<sub>2</sub>O<sub>3</sub> and more of Fe<sub>2</sub>O<sub>3</sub>
- (d) same quantity of Al<sub>2</sub>O<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub>

**Q.15** Match **List-I** (Apparatus) with **List-II** (Test) and select the correct answer using the codes given below the lists:

- | <b>List-I</b>                        | <b>List-II</b>                          |
|--------------------------------------|---|
| A. Vicat plunger with square needle  | 1. Initial setting time                 |
| B. Vicat plunger with annular collar | 2. Final setting time                   |
| C. Le-chatelier's                    | 3. Unsoundness due to lime and magnesia |
| D. Autoclave                         |   |

**List-II**

1. Initial setting time
2. Final setting time
3. Unsoundness due to lime and magnesia

4. Unsoundness due to lime only
5. Unsoundness due to magnesia only

**Codes:**

	A	B	C	D
(a)	1	2	3	5
(b)	2	1	4	5
(c)	2	1	5	3
(d)	1	2	4	3

**Q.16** For complete hydration of cement, the w/c ratio needed is

- (a) less than 0.25
- (b) more than 0.25 but less than 0.33
- (c) more than 0.33 but less than 0.40
- (d) more than 0.40 but less than 0.50

**Q.17** Consider the following:

1. lower heat of hydration
2. higher heat of hydration
3. lower shrinkage coefficient
4. higher shrinkage coefficient

The rapid hardening portland cement has a

- (a) 1 and 2 only
- (b) 2 and 3 only
- (c) 3 and 4 only
- (d) 2 and 4 only

**Q.18 Assertion (A) :** High alumina cement with calcium chloride additive is used while concreting in cold weather.

**Reason (R) :** Calcium chloride acts as an accelerator.

- (a) Both A and R are true and R is the correct explanation of A.
- (b) Both A and R are true but R is not a correct explanation of A.
- (c) A is true but R is false.
- (d) A is false but R is true.

**Q.19 Assertion (A):** Low heat portland cement is used in dam construction.

**Reason (R):** Low heat portland cement attains higher 28 days strength than ordinary portland cement.

- (a) Both A and R are true and R is the correct explanation of A.
- (b) Both A and R are true but R is not a correct explanation of A.

- (c) A is true but R is false.
- (d) A is false but R is true.

**Q.20** Select the INCORRECT statement:

- (a) 10 mm diameter plunger is used for consistency test.
- (b) 1 mm<sup>2</sup> needle attached to plunger is used for initial setting time.
- (c) 2 mm diameter annular collar is used for final setting time.
- (d) During performance of consistency test, temperature and relative humidity are maintained between (27 ± 2)°C and 90% respectively.

**Q.21** Consider the following:

1. C<sub>3</sub>S
2. C<sub>2</sub>S
3. C<sub>3</sub>A
4. C<sub>4</sub>AF

To produce low heat cement, it is necessary to reduce the compounds

- (a) 1 and 2
- (b) 1 and 3
- (c) 2 and 3
- (d) 3 and 4

**Q.22** Consider the following statements about Bogue's compound:

1. C<sub>3</sub>S enables clinker easy to grind, increases resistance to freezing and thawing.
2. C<sub>2</sub>S hydrates and hardens slowly and imparts resistance to chemical attack.

Which of the above statements are CORRECT?

- (a) 1 Only
- (b) 2 Only
- (c) 1 and 2
- (d) None of these

**Q.23** Match **List-I** (Type of cement) with **List-II** (Property/Characteristic) and select the correct answer using the codes given below the lists:

**List-I**

- A. High strength portland cement
- B. Super sulphated cement
- C. High alumina cement
- D. Rapid hardening portland cement

**List-II**

1. Should be used in the construction of sewers
2. Is extremely resistant to chemical attack
3. Gives a higher rate of heat development during hydration of cement
4. Has a higher content of tricalcium silicate

Codes:

	A	B	C	D
(a)	3	2	1	4
(b)	4	1	2	3
(c)	3	1	2	4
(d)	4	2	1	3

**Q.24 Assertion (A):** The tests for determining the setting times of cements are of little use in assessing the hardening of cement concrete.

**Reason (R):** Ultimate strength of concrete in-situ is not dependent upon the setting times of cement used.

- Both A and R are true and R is the correct explanation of A.
- Both A and R are true but R is not a correct explanation of A.
- A is true but R is false.
- A is false but R is true.

**Q.25** Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

**List-I**

- Air entraining Portland cement
- Low-heat Portland cement
- Hydrophobic Portland cement
- Rapid hardening Portland cement

**List-II**

- Suitable for very large structures
- Unsuitable for very large masses of concrete
- Greater resistance to frost attack
- Safe storage under unfavourable conditions of humidity

Codes:

	A	B	C	D
(a)	4	2	1	3
(b)	3	4	1	2
(c)	3	1	4	2
(d)	4	1	2	3

**Q.26** Consider the following statements:

- Both  $C_3S$  and  $C_2S$  give the same product on hydration.
- $C_2S$  hydrates slowly and provide much of the ultimate strength.
- $C_3S$  having a faster rate of reaction is accompanied by greater heat evolution.
- $C_3S$  provides more resistance to chemical attacks.

Incorrect statements among the above statements is/are

- 1 and 2
- 2 and 3
- 3 and 4
- 4 only

**Q.27** Consider the following statements:

- Tri-calcium silicate
- Di-calcium silicate
- Tri-calcium aluminate
- Tetra-calcium alumino ferrite

Which of the above is/are responsible for initial setting of cement?

- 1 only
- 2 and 3
- 3 and 4
- 1 and 2

**Q.28** Blast furnace slag has approximately

- 45% calcium oxide and about 35% silica.
- 50% alumina and 20% calcium oxide.
- 25% magnesia and 15% silica.
- 25% calcium sulphate and 15% alumina.

**Q.29** Consider the following statements:

- Presence of uncombined lime
- Binding qualities
- Insoluble residues
- Fineness of cement
- Setting time of cement

The object of soundness test of cement is to determine

- 1, 3 and 5
- 2, 3 and 4
- 1 and 2
- 1 only

**ANSWERS KEY**

1. (a) 2. (c) 3. (b) 4. (b) 5. (b)  
6. (a) 7. (b) 8. (c) 9. (d) 10. (b)  
11. (c) 12. (b) 13. (d) 14. (c) 15. (d)  
16. (a) 17. (d) 18. (d) 19. (c) 20. (c)  
21. (b) 22. (c) 23. (b) 24. (a) 25. (c)  
26. (d) 27. (c) 28. (a) 29. (d)

**HINTS & EXPLANATIONS**

8. (c)

High alumina content in cement makes it extremely resistant to chemical attack.

11. (c)

The four important constituents of cement are:

**Constituents**

**Percentage**

Lime (CaO)	—	60-67%
Silica (SiO <sub>2</sub> )	—	17-25%
Alumina (Al <sub>2</sub> O <sub>3</sub> )	—	3-8%
Iron Oxide (Fe <sub>2</sub> O <sub>3</sub> )	—	0.5-6%

14. (c)

The need to prepare sulphate resisting cement is the proneness of OPC towards sulphur.

The main constituents of OPC that are valuable to sulphur are C<sub>3</sub>A and C<sub>4</sub>AF. The ideal way to prepare sulphate resisting cement will be by reducing the concentration of Al<sub>2</sub>O<sub>3</sub> in raw material which will eventually produce less C<sub>3</sub>A and C<sub>4</sub>AF but concentration of Al<sub>2</sub>O<sub>3</sub> cannot be reduced feasibly.

So, excess Fe<sub>2</sub>O<sub>3</sub> is added in raw material which results in the formation C<sub>4</sub>AF at the expense of C<sub>3</sub>A which is less vulnerable to sulphate attack as compared to C<sub>3</sub>A.

16. (a)

Approximately 23% water by weight of cement is required for complete hydration of cement but 15% water is stuck in gel pores. Hence, 38% of water by weight of cement is to be added for complete hydration.

17. (d)

Rapid hardening portland cement has high content of C<sub>3</sub>S and C<sub>3</sub>A. Both these compounds generate high heat of hydration and has higher shrinkage coefficient.

18. (d)

A high alumina cement does not require admixture.

20. (c)

For final setting time, 5 mm diameter annular collar is used.

21. (b)

Low heat portland cement has low rate of evolution of heat and extends over a longer period. It has slower rate of gain of strength but the ultimate strength is same as that of portland cement. This is due to lower content of more rapidly hydrating compounds like C<sub>3</sub>S and C<sub>3</sub>A and increased content of C<sub>2</sub>S. Low rate of evolution of heat is advantageous in construction of large concrete structures like dams and spillways.

25. (c)

Low heat Portland cement can be used for mass concreting in very large structures while rapid hardening Portland cement is unsuitable for it.

Air entraining Portland cement provides greater resistance to frost attack and hydrophobic Portland cement can be stored safely under unfavourable conditions of humidity.

26. (d)

C<sub>3</sub>S does not provide any resistance to chemical attack.