

# Concrete Technology and Masonary Structures<sup>1</sup> Assignment<sup>2</sup>

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<sup>1</sup>This assignment covers various aspects of concrete technology and masonry structures, including theoretical principles and practical applications.

<sup>2</sup>This is an assignment given to students of Civil Engineering to enhance their understanding of the subject matter.

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# 1

# INTRODUCTION TO CONCRETE AND CONCRETE MATERIALS

*“Concrete is the single most widely used material in the world – and it has been used for centuries. It’s hard to imagine modern life without it.”*

– Robert Courland, *Concrete*

## 1.1 Use of concrete in structures and types of concrete

Concrete is a construction material obtained by mixing cementitious material, water, aggregates, and admixtures. When placed in forms and allowed to cure, it hardens into artificially built-up stones. Concrete is one of the most versatile and widely used construction materials in the world. Its applications range from simple sidewalks and pavements to complex structures like skyscrapers, dams, and bridges. The adaptability of concrete makes it suitable for a variety of forms and finishes, which can be adjusted to meet the specific needs of a project.

It is used widely throughout the world due to the following advantages:

### 1.1.1 Advantages

- Except for cement, concrete can be made from locally available coarse and fine aggregates, making it economical in the long run compared to other engineering materials.
- It has high compressive strength.
- It can be easily handled and molded into the desired shape.
- It requires very little maintenance.
- Concrete, along with steel, can be used to produce any desired structures.

Despite having the above-mentioned advantages, it has the following disadvantages:

### 1.1.2 Disadvantages

- With the rise and fall in temperature, concrete expands and shrinks. Hence, expansion joints have to be provided to avoid the formation of cracks.
- Fresh concrete shrinks on drying, and hardened concrete expands when getting moisture.
- Under sustained loading, creep develops in concrete. Therefore, provision for creep should be kept at the time of design.
- Concrete is not completely impervious.
- If concrete comes in contact with alkali and sulfate, it can lead to deterioration.

### 1.1.3 Types of Concrete

Concrete can be classified based on various criteria such as binding material, design purpose, and special properties.

#### Based on Binding Material

- i. Cement concrete
  - (a) Cement is used as a binding material.
  - (b) High compressive strength and relatively quick setting and hardening time as compared to lime concrete.
- ii. Lime concrete
  - (a) Lime is used as a binding material.
  - (b) Lower compressive strength as compared to cement concrete but higher workability and plasticity, and more breathable and flexible.

#### Based on Design

- i. Plain Cement concrete
  - (a) Plain concrete is concrete with no reinforcements.
  - (b) It is weak in tension but strong in compression..
- ii. Reinforced Cement concrete
  - (a) Reinforced concrete is concrete with reinforcements.
  - (b) This type of concrete can take extra compressive stresses, shear stresses, and tensile stresses as well.
- iii. Pre stressed Cement Concrete
  - (a) Pre-stressed concrete is concrete in which high compressive stresses are artificially induced before its actual use.
  - (b) This action strengthens the concrete against tensile forces, thereby improving its performance in service.

#### Based on density

- i. Lightweight Concrete
  - (a) concrete with a self-weight ranging between  $300 \text{ kg/m}^3$  to  $1850 \text{ kg/m}^3$  is called lightweight concrete.
  - (b) Lightweight aggregates like pumice, diatomite, rice husk, foamed slag, and bloated clay, etc., may be used to reduce the dead load of concrete. Such lightweight concrete is used in high-rise buildings to save money and manpower considerably.
- ii. Normal-weight Concrete
  - (a) Normal-weight concrete has a density of  $2400 \text{ kg/m}^3$ .
  - (b) It is produced using natural sand and crushed stones.
- ii. Heavyweight Concrete
  - (a) Concrete having a density in the range of  $3000 \text{ kg/m}^3$  to  $6000 \text{ kg/m}^3$  is called heavyweight concrete

- (b) This type of concrete is produced by using heavyweight aggregates like baryte, ferrophosphorus, goethite, and degreased scrap steel. Such concrete is used for the construction of nuclear radiation shield walls, ballast blocks, counterweights, sea walls, and other applications where high density is important.

### **Special Types of concretes**

i. Biological Concrete (Bacteriological Concrete)

Biological concrete incorporates bacteria that precipitate calcium carbonate, which enhances the concrete's self-healing properties and durability. This type of concrete is used to repair cracks autonomously, improving the longevity of structures.

ii. Self-Compacting Concrete

Self-compacting concrete (SCC) flows and settles into place under its own weight without the need for mechanical vibration. It is used in complex forms and structures where conventional compaction methods are impractical.

ii. Roller Compacted Concrete

Roller compacted concrete (RCC) is a dry mix concrete that is compacted using heavy rollers, making it suitable for use in large-scale pavements and dams. It offers high durability and strength with reduced construction costs.

ii. Fibre Reinforced Concrete

Fibre reinforced concrete (FRC) includes fibrous materials like steel, glass, or synthetic fibers to enhance its structural integrity. It improves the concrete's resistance to cracking, impact, and fatigue.

## **1.2 Concrete materials - Role of different materials (Aggregates, Cement, Water and Admixtures)**

### **1.2.1 Aggregates - Properties of aggregates and their gradation**

Aggregates are chemically inert, cost-effective materials dispersed throughout the cement paste to enhance the volume, stability, and durability of concrete. Their primary function is to provide a solid foundation that enhances the performance of concrete.

Aggregate must be of proper shape, clean, hard, strong and well graded since they cover 75 % of body of concrete. It should possess chemical stability, resistance to freezing and thawing and should exhibit abrasion resistance.

### **Classification of Aggregates**

Aggregates can be classified based on their geological origin, size, shape, and unit weight.

#### **A. Classification According to Geological Origin**

1. Natural Aggregates

These are sourced from natural deposits like sand and gravel, or from quarries by cutting rocks. They can be derived from any type of rock, such as igneous, sedimentary, or metamorphic. Examples: River gravel, crushed rock from quarries.

2. Artificial Aggregates

These are produced for specific purposes. Common examples include broken bricks and air-cooled blast-furnace slag. Examples: Crushed bricks, slag from steel mills.

## B. Classification According to Size

### 1. Fine Aggregate

Aggregates where most particles pass through a 4.75 mm IS sieve. These are typically composed of sand.

Examples: Natural sand, manufactured sand.

### 2. Coarse Aggregate

Aggregates where most particles are retained on a 4.75 mm IS sieve. They contain only small amounts of fine material as specified.

Examples: Gravel, crushed stone. These are described by nominal sizes such as 40 mm, 20 mm, 16 mm, and 12.5 mm.

### 3. All-In Aggregate

These are naturally available aggregates that include a mixture of fine and coarse particles. Adjustments in grading can be made by adding single-sized aggregates.

As per IS 383-1970, the grading of all-in aggregates should follow specific standards to ensure proper mixture and performance.

## Tables

Sieve Size	Percentage Passing	Remarks
10 mm	100	
4.75 mm	95-100	
2.36 mm	80-100	
1.18 mm	50-85	
600 $\mu\text{m}$	25-60	
300 $\mu\text{m}$	10-30	
150 $\mu\text{m}$	0-10	

Table 1.1: Grading of Fine Aggregates

Sieve Size	Percentage Passing	Remarks
40 mm	100	
20 mm	95-100	
16 mm	25-55	
12.5 mm	0-10	

Table 1.2: Grading of Coarse Aggregates

Sieve Size	Percentage Passing	Remarks
80 mm	100	
40 mm	95-100	
20 mm	45-75	
10 mm	25-45	
4.75 mm	0-10	

Table 1.3: Grading of All-In Aggregates

## C. Classification of Aggregates According to Shape

### 1. Rounded Aggregates

- Fully water-worn or completely shaped by attrition having minimum void percentage (approximately 33%).

## 1.2. CONCRETE MATERIALS - ROLE OF DIFFERENT MATERIALS (AGGREGATES, CEMENT, WATER AND ADMIXTURES)

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- These aggregates give minimum ratio of surface area to volume thus requiring minimal cement paste.
- Poor interlocking between particles, leading to inadequate bonding making it unsuitable for high-strength concrete.
- Typically found in natural deposits like riverbeds and seashores, wind blown sand.

### 2. Irregular Aggregates

- The aggregates having partially rounded particles having high percentage of voids ranging from 35 to 38%.
- It has better interlocking compared to rounded aggregates but is inadequate for high strength concrete but requires more cement paste for a given workability..
- Often sourced from riverbeds and gravel pits.

### 3. Angular Aggregates

- The aggregates with sharp, angular and rough particles with maximum percentage of voids (38 to 40%)
- Interlocking between particles is good and hence can be used for high strength concrete but aggregates require more cement paste to make workable concrete.
- Typically produced by crushing rocks.

### 4. Flaky Aggregates

- An aggregate is said to be flaky if its least dimension is less than 0.6% of its mean dimension.
- Generally not preferred.
- Tend to break under load.
- Reduce the strength and workability of concrete.
- Increase the cement requirement.

### 5. Elongated Aggregates

- An aggregate is said to be flaky if its greatest dimension is greater than 1.8% of its mean dimension.

### 6. Flaky and Elongated Aggregates

#### Characteristics:

- Both thin and long, combining the disadvantages of flaky and elongated shapes.
- Typically avoided in concrete construction due to poor performance.
- Result in poor workability and strength.
- Require more cement.
- Adversely affect the durability of concrete.

#### Note:

- Flaky particles should not exceed 10-15% by weight of the total aggregate.
- The combined flaky and elongated particles should not exceed 35-40% by weight of the total aggregate.

### Importance of Aggregate Shape

Selecting aggregates with the appropriate shape is crucial to achieving the desired properties in concrete construction. The shape of aggregates affects the following aspects of concrete:

1. **Workability:** Rounded aggregates provide better workability, while angular aggregates reduce workability.
2. **Strength:** Angular aggregates provide better interlocking and bonding, leading to higher strength.
3. **Durability:** Properly shaped aggregates help in achieving durable concrete by reducing the need for excess water and cement.
4. **Cement Requirement:** Angular and rough-textured aggregates require more cement to achieve the desired workability and strength compared to rounded aggregates.

By adhering to these classifications, aggregates can be effectively selected and used to produce concrete that is strong, durable, and economical.

### Classification of Aggregates Based on Unit Weight

Aggregates are classified according to their unit weights as normal weight, heavyweight, and lightweight aggregates.

#### 1. Normal Weight Aggregates

Description: These are the most commonly used aggregates in concrete construction.

Materials: Sands, gravels, crushed stones, brick ballast.

Specific Gravity: Typically between 2.5 and 2.7.

Applications: Used for general concrete work, including residential, commercial, and industrial structures.

Examples: Natural sand, gravel, crushed stone.

#### 2. Heavyweight Aggregates

Description: These aggregates have a higher density and are used to produce heavyweight concrete.

Materials: Baryte, ferro-phosphorus, goethite, hematite.

Applications: Mainly used for constructing radiation shielding structures, such as those found in nuclear power plants and medical facilities.

Specific Gravity: Generally greater than 3.0.

Examples: Hematite, Baryte

#### 3. Lightweight Aggregates

Description: These aggregates have a lower density and are used to produce lightweight concrete.

Materials: Can be natural or manufactured.

Natural: Diatomite, pumice, volcanic cinder.

Manufactured: Bloated clay, sintered fly ash.

Applications: - Reduce the self-weight of the structure. - Provide better thermal insulation. - Improve fire resistance.

Specific Gravity: Typically less than 2.0.

Examples: Diatomite, Pumice

### Properties of Aggregates

The properties and performance of concrete depend largely on the characteristics and properties of the aggregate. Generally, aggregates used in concrete should be clean, hard, strong, properly shaped, and well-graded. They must possess chemical stability, resistance to abrasion, and resistance to freezing and thawing. The properties of aggregates can be discussed under the following heads:

### A. Physical Properties

1. Shape

Same as classification according to shape.

2. Texture

Surface Texture: Measures the smoothness or roughness of the aggregate surface.

Types: Glassy, smooth, granular, rough, crystalline, porous, and honeycombed.

Impact on Concrete: Rough, porous textures increase the bond strength between aggregate and cement paste, enhancing compressive and flexural strength by up to 20%. Surface pores help develop a good bond through the suction of paste into these pores.

3. Specific Gravity

Definition: The ratio of the mass of solid in a given volume of the sample to the mass of an equal volume of water at the same temperature.

Types

- Absolute Specific Gravity: Ratio of the mass of solid to the weight of an equal void-free volume of water.
- Apparent/Bulk Specific Gravity: Volume of aggregate includes voids. It is the ratio of the mass of aggregate dried in an oven to the mass of water occupying a volume equal to that of solids including impermeable voids.

#### Formulae:

(a) Specific gravity =  $\frac{C}{A-B}$

(b) Apparent specific gravity =  $\frac{C}{C-B}$

(c) Water absorption =  $\frac{A-C}{C} \times 100$

Where:

- (a)  $A$  = mass of saturated surface dry aggregate
- (b)  $B$  = mass of saturated surface dry aggregate in water.
- (c)  $C$  = mass of oven dry aggregate in air

Typical Range: 2.5 to 2.8 for natural aggregates.

Importance: Higher specific gravity indicates harder and stronger aggregates.

4. Bulk Density: Definition: The mass of aggregate in a given volume, expressed in kg/m<sup>3</sup>. Factors: Depends on how densely the aggregate is packed, particle shape, size, grading, and moisture content.

5. Moisture Content:

Types:

- Saturated and Surface Dry (SSD): All pores are full of water.
- Dry Aggregate: Some water has evaporated after standing.

Bone Dry Aggregate: No moisture is left after oven drying.

Importance: Necessary for determining the net water-cement ratio during batching of concrete.

High Moisture Content: Increases effective water-cement ratio, reducing strength.

Dry Aggregate: Absorbs mixing water, potentially reducing workability.

6. Bulking of Sand:

Definition: Increase in volume of sand due to moisture content.

Impact: Affects mix proportion when using volume batching.

Cause: Moisture forms a film around sand particles, creating surface tension that pushes particles apart.

**Effect:** Can lead to a richer mix, increasing chances of segregation and honeycombing, and reducing yield.

**Behaviour:** Depends on the fineness of sand and moisture content. Increase in volume increases with moisture content. For increase in moisture content up to 5% to 8%, bulking may range up to 20% to 40% as shown in figure 1.1. With the further increase in moisture content, the volume of sand decrease till the sand is same as that of dry sand for same method of filling the container. Bulking occurs more in finer than in coarser sand.

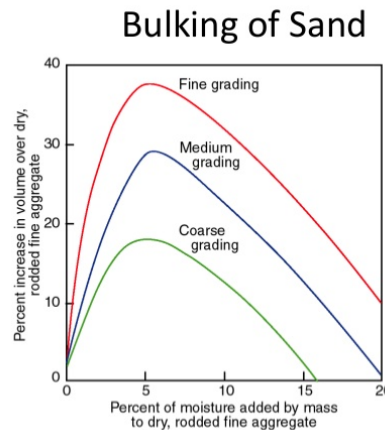


Figure 1.1: Bulking of sand.

### B. Chemical Properties

Aggregates are not completely inert and may contain reactive silica, which can react with the alkaline hydroxides (e.g.,  $\text{Na}_2\text{O}$ ) present in cement in the presence of water. This reaction forms alkali-silicate gel, which has unlimited swelling properties. When the gel absorbs water, it swells, causing disruption and cracking in the concrete, potentially leading to structural failure.

#### Factors Affecting Reactivity of Aggregates:

1. Particle Size and Porosity: Smaller, more porous particles increase the reactivity.
2. Quantity of Cement: Higher cement content can increase the risk of reaction.
3. Availability of Non-Evaporable Water: Essential for the alkali-silica reaction.  
item Permeability of Paste: Higher permeability allows more water to reach reactive sites.
4. Type of Aggregate: Some aggregates are more reactive due to their mineral composition.
5. Temperature: Optimal temperature for reaction is between  $10^\circ\text{C}$  and  $38^\circ\text{C}$ .

#### Control of Alkali-Aggregate Reaction:

1. Select non-reactive aggregates.
2. Use low-alkali cement (0.6% to 0.4% alkali content).
3. Use pozzolans and admixtures to mitigate the reaction.
4. Control void space in concrete.
5. Manage moisture and temperature conditions.



### C. Mechanical Properties

#### 1. Toughness

- Definition: Resistance of aggregate to failure under impact.
- Measurement: Aggregate Impact Value (AIV).
- Standards:
  - Should not exceed 45% by weight for general concrete.
  - Should not exceed 30% for concrete used in wearing surfaces.



Los Angeles Abrasion Testing Machine.

#### 2. Hardness

- Definition: Resistance of aggregate to wear and abrasion.
- Measurement: Aggregate Abrasion Value, determined by the Los Angeles Abrasion test.
- Standards:
  - Should not exceed 50% for concrete in non-wearing surfaces.
  - Should not exceed 30% for concrete in wearing surfaces.

#### 3. Crushing Strength

- Definition: Resistance of aggregate to failure under compressive load.
- Measurement: Aggregate Crushing Value (ACV).
- Standards:
  - Should not exceed 4% for general concrete.
  - Should not exceed 30% for concrete in wearing surfaces such as runways, roads, and pavements.

#### 4. Soundness

- Definition: Ability of aggregate to resist volume changes due to environmental conditions such as freezing and thawing, thermal changes, and wetting and drying cycles.
- Impact: Unsound aggregates can lead to deterioration, including local scaling, extensive surface cracking, or disintegration, compromising both the appearance and structural integrity of concrete.

### Fineness Modulus

Fineness modulus (FM) is a numerical index that provides an indication of the mean size of particles in a given aggregate sample. It is an essential factor in determining the overall fineness of aggregates used in concrete **Determination of Fineness Modulus:**

#### 1. Procedure:

- A sample of aggregate is sieved through a series of standard sieves with the following sizes: 80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm, 3.36 mm, 1.18 mm, 600  $\mu\text{m}$ , 300  $\mu\text{m}$ , and 150  $\mu\text{m}$ .
- The material retained on each sieve is recorded.

#### 2. Calculation:

- The cumulative percentage of the aggregate retained on each sieve is summed.

- The fineness modulus is calculated by dividing this sum by 100.

### 3. Interpretation:

- The fineness modulus is interpreted as a weighted average size of the sieves on which the material is retained. For instance, a fineness modulus of 6.0 suggests that the average size corresponds to the size of sixth sieve (4.75 mm) counted from the finest.
- Generally, the fineness modulus for fine aggregate varies between 2.0 to 3.5, for coarse aggregate between 5.5 to 8.0, and for all-in aggregate between 3.5 to 6.5.

## Grading of Aggregates

Grading of aggregates refers to the particle size distribution within an aggregate sample as determined by sieve analysis. Proper grading ensures dense concrete, requiring less cement paste and fine aggregate

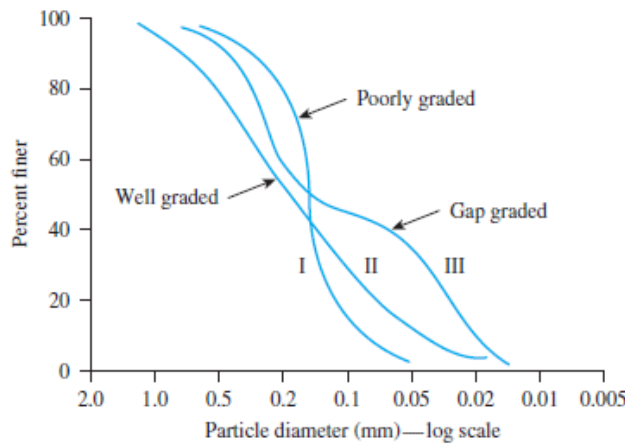


Figure 1.2: Gradation curve

As shown in Figure 1.4, The types of aggregates are:

### 1. Well-Graded Aggregates:

Definition: Well-graded aggregates have a wide range of particle sizes, with a good balance of fine, intermediate, and coarse particles.

Characteristics:

Contains a variety of particle sizes that fill voids and improve compaction.

Provides good workability, reduces segregation, and enhances the density and strength of concrete.

Uses: Ideal for making high-strength concrete, achieving good workability without excessive water content, and ensuring uniform distribution of aggregates in the mix.

### 2. Poorly-Graded Aggregates:

Definition: Poorly-graded aggregates have an insufficient range of particle sizes, lacking either fine or coarse particles.

Characteristics:

Contains mostly one size of particles, leading to poor compaction and increased voids.

Results in lower workability, increased risk of segregation, and reduced density and strength of concrete.

Uses: Generally not preferred for concrete production due to challenges in achieving desired properties and performance. However, they may be used in specific applications where uniformity of size is not critical.

### 3. Gap-Graded Aggregates:

Definition: Gap-graded aggregates have missing particle sizes within a certain range, creating

gaps or voids in the gradation curve.

Characteristics:

Contains a limited range of particle sizes, with some sizes omitted or sparsely represented.

Results in variable compaction, increased segregation risk around voids, and challenges in achieving optimal concrete properties.

Uses: Typically used in specialized applications where controlled voids or specific particle sizes are desired, such as in lightweight concrete or in decorative concrete finishes.

Choosing the right gradation of aggregates is crucial in concrete mix design to achieve the desired workability, strength, durability, and overall performance of concrete. Well-graded aggregates are generally preferred for most concrete applications due to their balanced particle size distribution, while poorly-graded and gap-graded aggregates may have limited uses in specific circumstances where their characteristics align with project requirements.

### 1.2.2 Cement - Manufacturing of cement, Compound composition of Portland cement, Structure and reactivity of compounds

## Cement: Definition, Classification, and Manufacturing Process

### Definition of Cement

Cement is a material with adhesive and cohesive properties that enable it to bond mineral fragments into a compact mass. The primary constituents of cement are compounds of lime. When water is added to cement, a chemical reaction known as hydration occurs, releasing a large quantity of heat. This reaction forms a gel that binds aggregates together, providing strength and water tightness upon hardening.

### Classification of Cement

Cement is mainly classified into two groups:

1. Natural Cement
2. Artificial Cement (Portland Cement)

### Manufacturing of Portland Cement

The manufacturing of Portland cement can be done by either the wet process or the dry process.

#### Dry Process

1. **Raw Materials:** The required proportions of calcareous (limestone, chalk, oyster shells, etc.) and argillaceous (clay, shale, slate, etc.) materials are mined.
2. **Crushing and Grinding:** The raw materials are crushed and ground into a fine powder.
3. **Mixing:** The ground materials are mixed in the correct proportions.
4. **Heating:** The mixture is fed into a rotary kiln and heated to about 1400°C-1500°C, forming clinkers or nodules with diameters of 5mm to 25mm.
5. **Cooling:** The clinkers are cooled and ground to the required fineness.
6. **Addition of Gypsum:** Gypsum ( $\text{CaSO}_4$ ) is added (2-3% by weight of clinker) to retard the setting time.
7. **Packaging:** The final product is bagged and transported to stockists and construction sites.

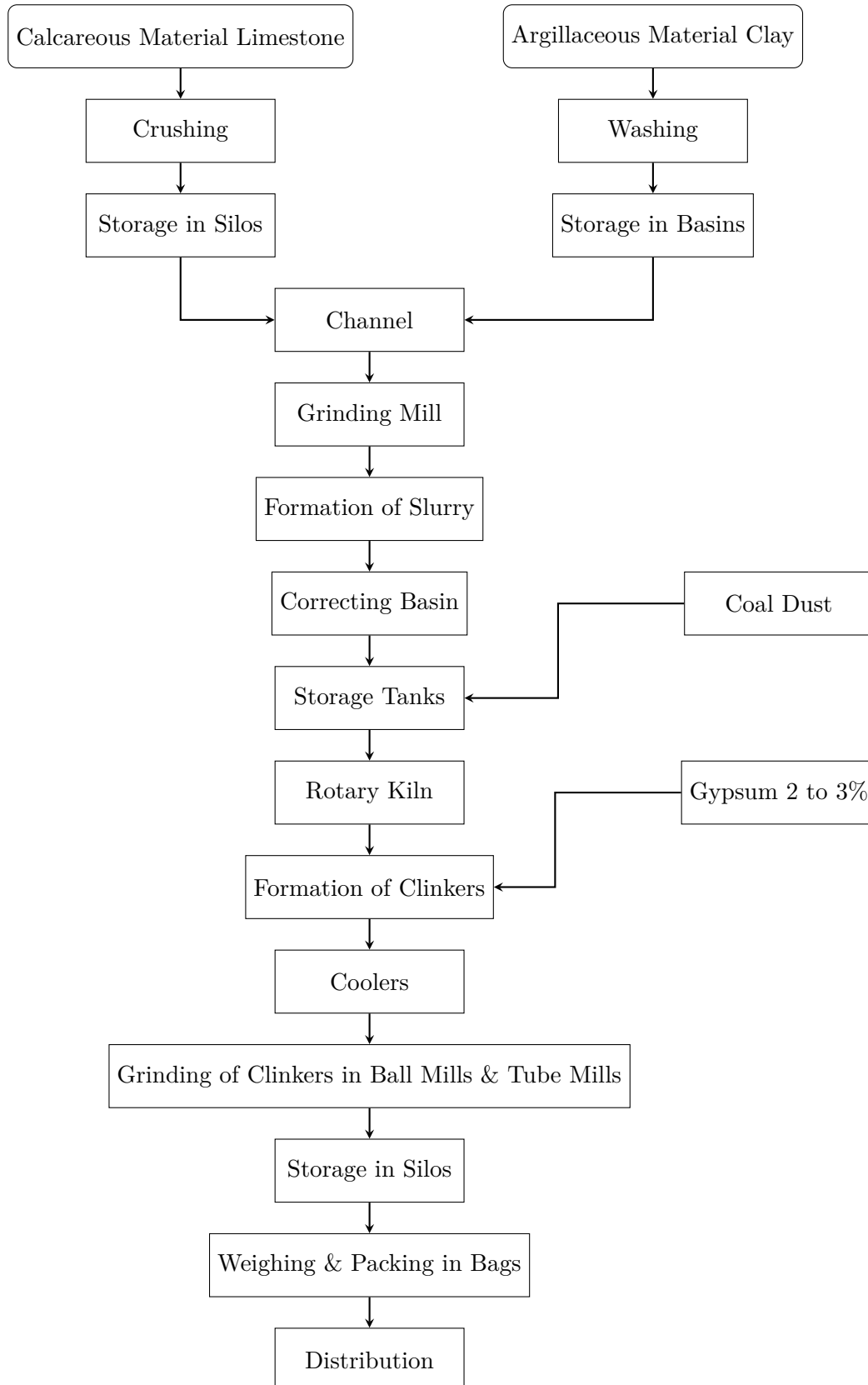


Figure 1.3: Cement Manufacturing Process

### Wet Process

1. **Raw Materials:** Similar raw materials are used as in the dry process.
2. **Crushing and Mixing:** The raw materials are crushed in mills and mixed with water to form a slurry.
3. **Heating:** The slurry is fed into the rotary kiln and heated to form clinkers.
4. **Cooling and Grinding:** The clinkers are cooled and ground to the required fineness.
5. **Addition of Gypsum:** Gypsum is added to retard the setting time.
6. **Packaging:** The final product is bagged and transported.

**Flow Chart of Cement Manufacturing Process**



**Ingredients and Their Functions**

**Compound Composition of Portland Cement**

The composition of Portland cement mainly consists of the following four compounds:

<b>Ingredient</b>	<b>Proportion (%)</b>	<b>Function</b>
Lime (CaO)	60-65	Controls strength and soundness
Silica (SiO <sub>2</sub> )	17-25	Provides strength; excess slows setting
Alumina (Al <sub>2</sub> O <sub>3</sub> )	3-8	Helps in setting but lowers strength
Ferrous Oxide (Fe <sub>2</sub> O <sub>3</sub> )	0.5-6	Provides color and helps in fusion
Magnesium Oxide (MgO)	0.5-4	Provides color and hardness; excess causes cracks
Sulphur Trioxide (SO <sub>3</sub> )	1-2	Makes cement sound; excess causes unsoundness
Soda and Potash (Na <sub>2</sub> O and K <sub>2</sub> O)	0.5-1.3	Excess causes efflorescence and cracking

Table 1.4: Ingredients and Their Functions

<b>Compound</b>	<b>Chemical Formula</b>	<b>Abbreviation</b>	<b>Mass (%)</b>
Tricalcium Silicate	3CaO·SiO <sub>2</sub>	C <sub>3</sub> S	25-50
Dicalcium Silicate	2CaO·SiO <sub>2</sub>	C <sub>2</sub> S	20-45
Tricalcium Aluminate	3CaO·Al <sub>2</sub> O <sub>3</sub>	C <sub>3</sub> A	5-12
Tetracalcium Aluminoferrite	4CaO·Al <sub>2</sub> O <sub>3</sub> ·Fe <sub>2</sub> O <sub>3</sub>	C <sub>4</sub> AF	6-12

Table 1.5: Compound Composition of Portland Cement

## Properties of Cement Compounds

### 1. Tricalcium Silicate (C<sub>3</sub>S)

- Develops early strength and hardness.
- Generates more heat of hydration.
- Less resistant to sulfate attack.
- Hydrates and hardens rapidly.

### 2. Dicalcium Silicate (C<sub>2</sub>S)

- Hydrates and hardens slowly.
- Generates less heat of hydration.
- More resistant to sulfate attack.
- Responsible for ultimate strength.

### 3. Tricalcium Aluminate (C<sub>3</sub>A)

- Hydrates rapidly.
- Less resistant to sulfate attack.
- Contributes little to the strength of cement.
- Reacts rapidly with water and generates high heat of hydration, leading to initial set.

### 4. Tetracalcium Aluminoferrite (C<sub>4</sub>AF)

- Has less cementing value.
- Reacts very slowly and is responsible for increasing the volume of cement and reducing cost.

## Bogue's Equation

The four compounds of cement are called Bogue's compounds. The percentage of major compounds in cement can be obtained from Bogue's equations given below:

$$\begin{aligned}C_3S &= 4.07(\text{CaO}) - 7.60(\text{SiO}_2) - 6.72(\text{Al}_2\text{O}_3) - 1.43(\text{Fe}_2\text{O}_3) - 2.85(\text{SO}_3) \\C_2S &= 2.87(\text{SiO}_2) - 0.754(C_3S) \\C_3A &= 2.65(\text{Al}_2\text{O}_3) - 1.69(\text{Fe}_2\text{O}_3) \\C_4AF &= 3.04(\text{Fe}_2\text{O}_3)\end{aligned}$$

### Example Calculation

From Bogue's equations, calculate the different compounds of cement with the following oxide composition:

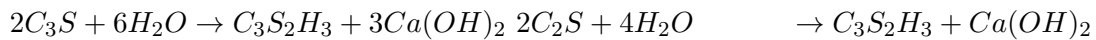
$$\begin{aligned}\text{CaO} &= 61.0\% \\ \text{SiO}_2 &= 25.0\% \\ \text{Fe}_2\text{O}_3 &= 3.0\% \\ \text{Al}_2\text{O}_3 &= 4.0\% \\ \text{SO}_3 &= 2.5\% \\ \text{Free lime} &= 1.0\%\end{aligned}$$

$$\begin{aligned}C_3S &= 4.07(61.0) - 7.60(25.0) - 6.72(4.0) - 1.43(3.0) - 2.85(2.5) \\ &= 248.27 - 190.0 - 26.88 - 4.29 - 7.125 \\ &= 19.975 \approx 20\% \\ C_2S &= 2.87(25.0) - 0.754(20) \\ &= 71.75 - 15.08 \\ &= 56.67\% \\ C_3A &= 2.65(4.0) - 1.69(3) \\ &= 10.60 - 5.07 \\ &= 5.53\% \\ C_4AF &= 3.04(3.0) \\ &= 9.12\%\end{aligned}$$

### Hydration of Cement

Anhydrous cement does not bind fine and coarse aggregates; it acquires binding properties only when mixed with water. The chemical reaction between cement and water is called hydration of cement.

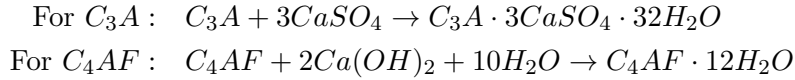
When water is added to cement,  $C_3S$  undergoes hydrolysis first, producing  $C_3S_2H_3$  (calcium silicate hydrate) and  $\text{Ca}(\text{OH})_2$  is released. Then,  $C_2S$  hydrates. In equation form:



From the above equations, it is clear that both silicates require the same quantity of water for hydration, but  $C_2S$  produces less than half of the  $\text{Ca}(\text{OH})_2$  produced by  $C_3S$ .  $\text{Ca}(\text{OH})_2$  is not desirable in concrete as it can get leached during service, making concrete porous. Thus, in hydraulic structures, cement with higher  $C_2S$  content should be used.

The reaction of  $C_3A$  with water is very violent, leading to immediate stiffening of the paste called flash-set. To prevent flash-set, 2-3% of gypsum ( $\text{CaSO}_4$ ) is added to cement clinker. Gypsum reacts with  $C_3A$  to form insoluble calcium sulfoaluminate, which deposits on the surface of  $C_3A$ , forming a protective colloidal membrane and thus retarding the direct hydration reaction.





## Rate of Hydration and Strength Gain

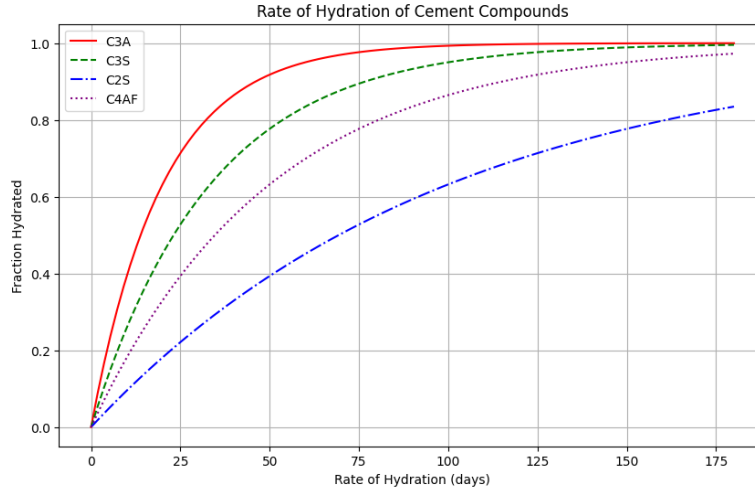


Figure 1.4: Rate of Hydration of cement Compounds.

The above graph shows the rate of hydration of  $C_2S$  is lesser than that of  $C_3S$ . The order of rate of reaction is  $C_3A$ ,  $C_3S$ ,  $C_2S$ , and  $C_4AF$ . The order of gain of strength is  $C_3S$ ,  $C_2S$ ,  $C_3A$ , and  $C_4AF$ .

### 1.2.3 Introduction to Special type of cement

#### 1. Ordinary Portland Cement (OPC)

Ordinary Portland Cement (OPC) is widely used for general concrete construction. It is suitable for applications where the concrete is not exposed to sulphates in soil or groundwater. OPC has a medium rate of strength development and heat generation. It is available in different grades such as 33, 43, and 53. The specific surface area of OPC is approximately  $2250 \text{ cm}^2/\text{g}$ .

#### 2. Rapid Hardening Cement

Rapid Hardening Cement develops strength much faster than OPC. This is due to its higher content of  $C_3S$  (tricalcium silicate), which contributes to the increased rate of strength gain. The specific surface area of Rapid Hardening Cement is around  $3250 \text{ cm}^2/\text{g}$ . Despite its rapid strength gain, the initial and final setting times are similar to those of OPC. This type of cement is particularly useful in cold weather, road construction, and situations where formwork needs to be removed quickly. The strength developed by Rapid Hardening Cement in 1 day is of the order of the 3-day strength of OPC, and the 3-day strength of Rapid Hardening Cement is of the order of the 7-day strength of OPC with the same water-cement ratio.

#### 3. Extra Rapid Hardening Portland Cement

Extra Rapid Hardening Portland Cement is made by adding calcium chloride to Rapid Hardening Cement. The calcium chloride content should not exceed 2%. This cement achieves about 25% higher strength than Rapid Hardening Cement within 1 or 2 days and 10-20% higher strength at 7 days. However, the strength gain advantage diminishes after 90 days. This cement has a very short setting time, ranging from 5 to 30 minutes depending on the ambient temperature, and it should not be stored for more than one month after manufacturing.



#### 4. Low Heat Portland Cement

Low Heat Portland Cement is designed to reduce the heat of hydration. It has lower C3S and C3A content and higher C2S content compared to OPC. This results in a slower rate of strength development initially, but the ultimate strength is similar to that of OPC. The setting and hardening times of this cement are nearly same as that of ordinary portland cement. Its strength after 7 days is 50% that of OPC and after 28 days 66%. The specific surface area of this cement is about 3200 cm<sup>2</sup>/g. It is suitable for mass concrete structures like dams and bridges where controlling the heat of hydration is crucial.

#### 5. Sulphate Resisting Cement

Sulphate Resisting Cement is a type of Portland cement with low C3A (less than 5%) and C4AF content. It is highly effective against sulphate attack, making it ideal for structures exposed to aggressive environments, such as marine conditions. This cement type has a high silicate content and resists the expansion and cracking caused by sulphate reactions in hardened concrete.

#### 6. Water Proof Portland Cement

Waterproof Portland Cement is created by adding waterproofing agents like calcium stearate, aluminium stearate, and gypsum treated with tannic acid to ordinary Portland cement during mixing. This type of cement is used in water-retaining structures such as tanks and reservoirs.

#### 7. White Portland Cement

White Portland Cement is similar to ordinary Portland cement but with a reduced iron oxide content (less than 1%). It is used for architectural purposes where aesthetic considerations are important. The specific gravity of white cement is slightly lower than that of OPC (3.05 to 3.10), and its strength is also somewhat lower.

#### 8. Colored Portland Cement

Colored Portland Cement is produced by adding up to 10% coloring pigments to ordinary Portland cement during grinding. The pigments used should be permanent and suitable for architectural applications. This type of cement is used for decorative purposes.

### 1.2.4 Use of water in concrete

Water is a crucial yet relatively inexpensive ingredient in concrete. Its primary roles include participating in the hydration process and providing lubrication between fine and coarse aggregates, thus enhancing the workability of concrete. Additionally, water is essential for curing concrete and washing aggregates.

#### Quality of Mixing Water

The quality of water used for mixing concrete should adhere to the following standards:

1. **Potability:** Water that is fit for drinking is also generally suitable for making concrete. However, water containing up to 0.05% sugar by weight is acceptable for drinking but can delay the initial setting time of cement by about 4 hours. Therefore, water used for concrete production must be free from acids, oils, carbonates, bicarbonates, alkalis, sugars, silt, and organic materials that could adversely affect both fresh and hardened concrete.
2. **pH Value:** The pH value of mixing water should be between 6 and 8 to ensure optimal performance.

3. **Algae:** If algae are present in mixing water, they can combine with cement and reduce the bond strength between aggregates and the cement paste. Hence, water should be free from algae.
4. **Chlorides:** Water should be free from chlorides, commonly found in seawater, as they can lead to the corrosion of reinforcement.
5. **Compressive Strength:** If the compressive strength of concrete mixed with the given water is at least 90% of the strength achieved with distilled water, then the water is considered acceptable for concrete production.

### Water for Washing Aggregates

Impure water used for washing aggregates can result in the deposition of salts, silt, organic matter, and other impurities on the aggregate particles. This coating forms a layer between the cement gel and aggregate surface, weakening the bond and ultimately reducing the strength of the concrete. Therefore, water used for washing aggregates should be free from such impurities.

### Water for Curing Concrete

Water suitable for mixing concrete is also appropriate for curing. However, certain precautions should be taken:

1. **Iron or Organic Matter:** The presence of iron or organic matter in curing water may cause staining of concrete, particularly if the flow of water is slow and evaporation is rapid.
2. **Carbon Dioxide:** Water should be free from carbon dioxide ( $\text{CO}_2$ ) as it can attack hardened concrete.
3. **Melting Ice or Condensation:** Water formed by melting ice or condensation should not be used for curing as it contains minimal  $\text{CO}_2$ , which can dissolve calcium hydroxide ( $\text{Ca}(\text{OH})_2$ ) and cause surface erosion.
4. **Sea Water:** Sea water is prohibited for curing purposes due to the high salt content, which can lead to deterioration of the concrete.

### 1.2.5 Admixtures - Classification of admixtures, Introduction to commonly used admixtures (Super-plasticizer, Water proofing agent and Retarders), Use of Mineral admixtures in concrete

Admixtures are chemical compounds other than hydraulic cement, water, and aggregates, added to concrete mix immediately before or during mixing to modify one or more properties of fresh or hardened concrete. The primary aim of using admixtures is to achieve improvements in the properties of concrete that cannot be economically attained by adjusting the proportions of cement, aggregate, and water alone. However, it is important to note that admixtures are not a substitute for good workmanship. They should be used only after thoroughly assessing their effects on the concrete for the intended application. Commonly modified properties include the rate of hydration, dispersion, air-entrainment, and workability.

## Functions and Benefits of Admixtures

Admixtures are used for the following purposes:

1. To accelerate strength development at early ages.
2. To retard the initial setting time of concrete.
3. To improve workability of concrete.

4. To reduce segregation in grout or concrete mixes.
5. To increase the strength of concrete by reducing water content and densifying the concrete.
6. To enhance the durability properties of concrete.
7. To aid in the curing process of concrete.
8. To reduce shrinkage during the setting of concrete.
9. To reduce bleeding of concrete.
10. To impart color to concrete.
11. To reduce the heat of hydration.
12. To enhance the bond of concrete to steel reinforcement.
13. To increase resistance to chemical attacks.
14. To increase the impermeability of concrete.
15. To decrease the weight of concrete per cubic meter.
16. To control the alkali-aggregate reaction.
17. To produce cellular concrete.
18. To impart color to the concrete surface.

## Classification of Admixtures

Admixtures can be classified into the following two categories:

1. **Chemical Admixtures**
2. **Mineral Admixtures**
3. **Natural Mineral Admixtures**

### A. Chemical Admixtures

Chemical admixtures are typically in the form of powders or fluids added to the concrete mix to improve or impart specific properties to fresh or hardened concrete. They include the following types:

#### 1. Accelerating Admixtures (Accelerators)

**Definition:** Accelerators are admixtures used to speed up the initial setting time of concrete. They are particularly useful in cold weather conditions and for rapid repair needs.

**Functions:**

- **Accelerate Setting Time:** These admixtures accelerate the initial setting time of concrete. This allows for early removal of formwork, reduces the required curing period, and permits earlier use of the structure.
- **Useful in Cold Weather:** They are especially useful in cold weather conditions where the setting time of concrete is significantly slowed.
- **Rapid Repairs:** Ideal for situations requiring rapid repairs, such as waterfront structures in tidal zones or underwater concreting.

**Common Accelerators:**

- Calcium chloride ( $\text{CaCl}_2$ )
- Sodium hydroxide ( $\text{NaOH}$ )
- Sodium sulfate ( $\text{Na}_2\text{SO}_4$ )
- Sodium carbonate ( $\text{Na}_2\text{CO}_3$ )
- Potassium hydroxide ( $\text{KOH}$ )

**2. Retarding Admixtures (Retarders)**

**Definition:** Retarders are admixtures that slow down the initial rate of hydration, thereby increasing the setting time of the concrete mix.

**Functions:**

- **Slow Setting Time:** Retarders slow down the initial rate of hydration, thereby increasing the setting time of the concrete mix. This is beneficial in hot weather conditions to counteract the accelerating effects of high temperatures and to keep concrete workable for extended periods.
- **Long-Distance Transport:** Useful in situations where concrete must be transported over long distances without setting prematurely.

**Common Retarders:**

- Gypsum
- Sugars
- Calcium borate
- Hydroxides of zinc and lead

**3. Air-Entraining Admixtures**

**Definition:** Air-entraining admixtures are added to concrete to introduce tiny air bubbles, which improve its workability and durability, especially in freeze-thaw environments.

**Functions:**

- **Incorporate Air:** These admixtures incorporate controlled amounts of air throughout the concrete, enhancing workability and durability.
- **Resistance to Frost:** They improve resistance to frost action, reducing the likelihood of damage in freeze-thaw conditions.
- **Reduce Bleeding and Segregation:** Decrease the bleeding and segregation of the concrete mix.

**Common Air-Entraining Agents:**

- Olive oil
- Tallow
- Stearic and oleic acids
- Abietic acid
- Synthetic detergents

#### 4. Plasticizers (Water-Reducing Admixtures)

**Definition:** Plasticizers are additives that reduce the water-cement ratio of concrete, improving its workability without compromising strength.

**Functions:**

- **Reduce Water-Cement Ratio:** Plasticizers reduce the water-cement ratio while maintaining workability, or increase workability at a constant water-cement ratio.
- **Increase Strength:** Reducing the water content leads to higher strength concrete.

**Common Plasticizers:**

- Derivatives of lignosulfonic acids and their salts
- Hydroxylated carboxylic acids

#### 5. Superplasticizers (High-Range Water-Reducing Admixtures)

**Definition:** Superplasticizers are high-range water reducers that allow for significant reductions in water content while maintaining fluidity, resulting in high-strength and highly workable concrete.

**Functions:**

- **Significant Water Reduction:** Superplasticizers significantly reduce water content (by up to 20 to 40%) and are used to produce flowing concrete for use in inaccessible locations, quick placements, and high-strength, high-performance concrete.

**Common Superplasticizers:**

- Sulfonated melamine formaldehyde condensates (SMF)
- Sulfonated naphthalene formaldehyde condensates (SNF)
- Modified lignosulfonates (MLS)

### B. Mineral Admixtures

Mineral admixtures are supplementary cementing materials that are finely ground siliceous materials. They react chemically with calcium hydroxide released during the hydration of Portland cement to form compounds with cementing properties. Mineral admixtures are added to concrete to make the mix more economical, reduce permeability, increase strength, or influence other properties.

#### 1. Fly Ash

**Source:** A by-product from the combustion of pulverized coal in electric power plants.

**Functions:**

- **Improves Workability:** Fly ash particles are spherical and act as ball bearings, reducing the water demand and improving the workability of the concrete mix.
- **Increases Strength and Durability:** Reacts with calcium hydroxide to form additional cementitious compounds, enhancing the long-term strength and durability.
- **Reduces Heat of Hydration:** Lowers the heat generated during the cement hydration process, minimizing thermal cracking in mass concrete structures.

## 2. Silica Fume

**Source:** A by-product of the production of silicon and ferrosilicon alloys.

**Functions:**

- **Enhances Strength:** The ultra-fine particles fill the spaces between cement grains, leading to a denser and stronger concrete.
- **Improves Durability:** Increases resistance to chemical attacks and reduces permeability, protecting against chloride ingress and sulfates.
- **Reduces Bleeding:** Helps in minimizing the movement of water to the surface, reducing surface bleeding.

## 3. Ground Granulated Blast Furnace Slag (GGBFS)

**Source:** A by-product of iron production in blast furnaces.

**Functions:**

- **Improves Strength and Durability:** Contributes to the formation of additional cementitious compounds, enhancing long-term strength and resistance to aggressive environments.
- **Reduces Heat of Hydration:** Similar to fly ash, GGBFS reduces the heat generated during the hydration process.
- **Enhances Workability:** Provides a smoother, more workable mix.

## 4. Metakaolin

**Source:** Obtained by calcining pure or refined kaolinite clay at temperatures of 650°C to 850°C and then grinding it.

**Functions:**

- **Enhances Strength:** Highly reactive pozzolan that improves the compressive strength of concrete.
- **Reduces Permeability:** Densifies the microstructure, reducing the permeability and enhancing durability.
- **Improves Workability:** Enhances the workability of the concrete mix, making it easier to handle and place.

## C. Natural Mineral Admixtures

Natural mineral admixtures are supplementary cementing materials that enhance the properties of concrete by reacting with calcium hydroxide to form additional cementitious compounds. These materials are often derived from natural sources and offer several benefits, including improved durability, reduced permeability, and increased long-term strength. Below are three common types of natural mineral admixtures:

### a. Volcanic Ash

Volcanic ash is a natural pozzolan derived from volcanic eruptions. It consists primarily of fine, glassy particles that are highly reactive in the presence of calcium hydroxide.

- **Source:** Naturally occurring volcanic ash deposits.
- **Functions:**

- **Improves Durability:** Reacts with calcium hydroxide to form additional cementitious compounds, enhancing resistance to chemical attacks.
- **Increases Strength:** Contributes to long-term strength development, making concrete more robust.
- **Reduces Permeability:** Creates a denser concrete matrix, lowering its permeability and improving its resistance to water infiltration.

### b. Clay and Shales

Clay and shales are natural materials that, when processed appropriately, can act as effective pozzolanic materials in concrete.

- **Source:** Naturally occurring clay and shale deposits.
- **Functions:**
  - **Enhances Durability:** Reacts with calcium hydroxide to produce additional cementitious materials, improving the durability of concrete.
  - **Improves Workability:** The fine particles of processed clay and shales improve the workability of the concrete mix.
  - **Increases Strength:** Contributes to the long-term strength of concrete through pozzolanic reactions.

### c. Calcined Diatomaceous Earth

Calcined diatomaceous earth is a natural pozzolan obtained from the heat treatment of diatomaceous earth, which is composed of fossilized remains of diatoms.

- **Source:** Diatomaceous earth deposits subjected to calcination.
- **Functions:**
  - **Increases Strength:** Calcination enhances the pozzolanic activity, leading to increased strength of the concrete.
  - **Improves Durability:** Reacts with calcium hydroxide to form stable cementitious compounds, enhancing resistance to environmental degradation.
  - **Reduces Permeability:** Results in a denser concrete matrix, reducing its permeability and enhancing its resistance to water ingress and chemical attack.

In summary, natural mineral admixtures such as volcanic ash, clay and shales, and calcined diatomaceous earth provide significant benefits to concrete by enhancing its durability, strength, and resistance to environmental factors. Their incorporation into concrete mixes can lead to more sustainable and resilient structures.