Chapter 5: Chemical and Mineral Admixtures

Introduction

Concrete, the most widely used construction material globally, is versatile and durable. However, it often needs modifications in its fresh or hardened state to meet the demands of specific projects. This is where **admixtures** play a critical role. Admixtures are materials other than water, aggregates, cement, and fibers that are added to concrete either before or during mixing to modify its properties.

This chapter delves into the **two broad categories of admixtures: Chemical and Mineral**, examining their composition, functionality, types, mechanisms, and applications in concrete technology.

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1. Admixtures: Classification

1.1 Based on Function

- **Chemical admixtures** – Modify fresh and hardened concrete behavior (e.g., set time, workability, etc.).
- **Mineral admixtures** – Enhance concrete's long-term properties (e.g., strength, durability, workability).

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2. Chemical Admixtures

Chemical admixtures are typically water-soluble and are added in small dosages (usually less than 5% by weight of cement). They influence concrete hydration, workability, setting time, and more.

2.1 Types of Chemical Admixtures

2.1.1 Water-Reducing Admixtures (Plasticizers)

- **Purpose:** Increase workability without adding water, or maintain workability with less water.
- **Mechanism:** Disperse cement particles using surface-active agents, reducing friction.
- **Examples:** Lignosulfonates, Hydroxycarboxylic acids.

- **Applications:** Pumped concrete, precast elements, normal concrete where lower w/c ratio is needed.

2.1.2 Superplasticizers (High Range Water Reducers)

- **Purpose:** Significant increase in workability or reduction of water (up to 30%).
- **Mechanism:** Electrostatic repulsion or steric hindrance between cement particles.
- **Examples:** Sulfonated melamine formaldehyde (SMF), Polycarboxylate ethers (PCE).
- **Applications:** High-performance concrete, self-compacting concrete (SCC), heavily reinforced sections.

2.1.3 Retarders

- **Purpose:** Delay setting time of concrete.
- **Mechanism:** Adsorb on cement particles, slowing down hydration.
- **Examples:** Gypsum, sugars, lignosulfonates, phosphates.
- **Applications:** Large pours, hot weather concreting, to prevent cold joints.

2.1.4 Accelerators

- **Purpose:** Speed up setting and early strength gain.
- **Mechanism:** Promote faster hydration of C3S and C3A phases in cement.
- **Examples:** Calcium chloride ($CaCl_2$), calcium nitrate, thiocyanates.
- **Applications:** Cold weather concreting, early formwork removal, precast concrete.

Note: Calcium chloride should not be used with reinforced concrete due to corrosion risks.

2.1.5 Air-Entraining Admixtures

- **Purpose:** Introduce microscopic air bubbles in concrete.
- **Mechanism:** Stabilize air bubbles during mixing using surfactants.
- **Examples:** Vinsol resin, synthetic detergents, fatty acids.
- **Applications:** Freeze-thaw resistance, increased durability, workability improvement.

2.1.6 Shrinkage-Reducing Admixtures

- **Purpose:** Minimize drying shrinkage and cracking.
- **Mechanism:** Reduce surface tension of water in pores, decreasing capillary stress.
- **Examples:** Polypropylene glycol derivatives.

- **Applications:** Bridge decks, industrial floors, repair works.

2.1.7 Corrosion Inhibitors

- **Purpose:** Protect reinforcement from corrosion.
- **Mechanism:** Form protective film on rebars or increase pH.
- **Examples:** Calcium nitrite, sodium benzoate.
- **Applications:** Marine structures, parking garages, bridges.

2.1.8 Bonding Agents

- **Purpose:** Improve bond between old and new concrete layers.
- **Mechanism:** Adhesion-promoting polymers like styrene butadiene.
- **Examples:** Epoxy resins, acrylic latexes.
- **Applications:** Repair works, overlays.

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3. Mineral Admixtures (Supplementary Cementitious Materials – SCMs)

Mineral admixtures are finely divided siliceous or alumino-siliceous materials that react with calcium hydroxide (CH) during cement hydration to form additional C-S-H gel, enhancing the properties of concrete.

3.1 Types of Mineral Admixtures

3.1.1 Fly Ash

- **Source:** By-product of coal combustion in thermal power plants.
- **Types:** Class F (low CaO), Class C (high CaO).
- **Properties:**
  - Pozzolanic in nature.
  - Improves workability, long-term strength, and sulfate resistance.
  - Reduces permeability and heat of hydration.
- **Dosage:** 15–35% of cement weight.
- **Applications:** Mass concreting, pavements, RCC.

3.1.2 Silica Fume (Microsilica)

- **Source:** By-product of silicon/ferrosilicon alloy production.
- **Properties:**

- Very fine, high surface area.
- High pozzolanic activity.
- Increases strength, reduces permeability drastically.

- **Dosage:** 5–10%.
- **Applications:** High-strength concrete, marine structures, industrial floors.

3.1.3 Ground Granulated Blast Furnace Slag (GGBS)

- **Source:** By-product of iron production in blast furnaces.
- **Properties:**
  - Latent hydraulic material.
  - Improves workability and long-term durability.
  - Lowers heat of hydration and enhances sulfate resistance.
- **Dosage:** 30–50%.
- **Applications:** Marine works, sewage treatment plants, mass concrete.

3.1.4 Metakaolin

- **Source:** Calcined kaolinite clay.
- **Properties:**
  - High pozzolanic reactivity.
  - Improves early strength, durability, and resistance to alkali-silica reaction (ASR).
- **Dosage:** 5–15%.
- **Applications:** White/colored concrete, architectural and durable concrete.

3.1.5 Rice Husk Ash (RHA)

- **Source:** Controlled combustion of rice husks.
- **Properties:**
  - High silica content, highly pozzolanic.
  - Enhances strength, durability, and chloride resistance.
- **Dosage:** 10–20%.
- **Applications:** Sustainable construction, rural construction, eco-concrete.

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4. Mechanism of Pozzolanic Reaction (Mineral Admixtures)

The pozzolanic reaction occurs between calcium hydroxide [$Ca(OH)_2$], released during hydration of Portland cement, and the reactive silica (SiO_2) or alumina (Al_2O_3) in the mineral admixtures. The basic reaction is:

$Ca(OH)_2 + SiO_2 \rightarrow$ C-S-H (Calcium Silicate Hydrate)

This secondary C-S-H gel improves the microstructure by:

- Reducing porosity.
- Increasing density.
- Enhancing long-term strength and impermeability.

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5. Comparison: Chemical vs. Mineral Admixtures

Aspect	Chemical Admixtures	Mineral Admixtures
Nature	Organic/inorganic chemicals	Finely divided pozzolanic/hydraulic solids
Dosage	< 5% by weight of cement	5–50% by weight of cement
Timing	Used to control short-term properties	Modify long-term behavior
Function	Workability, setting time, air entrainment	Strength, durability, sustainability
Cost	Generally higher	Lower (by-product reuse)
Example	Superplasticizer, retarder	Fly ash, silica fume

6. IS Standards and Codal Provisions

- **IS 9103:1999** – Specification for concrete admixtures.
- **IS 456:2000** – Provides guidance on use of mineral admixtures.
- **IS 3812 (Part 1 & 2)** – Specification for fly ash.

- **IS 12089:1987** – Specification for granulated slag.
- **IS 15388:2003** – Specification for silica fume.

Proper testing and compatibility trials are essential before incorporating admixtures in concrete mix design to ensure desired performance.

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7. Compatibility of Admixtures with Cement

7.1 Factors Affecting Compatibility

The performance of an admixture depends on its **interaction with cement**. Factors affecting compatibility include:

- **Cement composition:** High C3A or alkali content can affect retarder and superplasticizer performance.
- **Fineness of cement:** Finer cement accelerates hydration, requiring different admixture dosage.
- **Mix water chemistry:** Sulfates or chlorides in water can alter admixture behavior.
- **Temperature:** High temperatures can accelerate or retard chemical reactions unpredictably.
- **Time between mixing and placing:** Some admixtures lose effectiveness over time (known as "slump loss").

7.2 Solutions for Compatibility Issues

- Use admixture trial mixes with project-specific cement.
- Consult manufacturer for compatibility charts.
- Modify dosage or combine admixtures carefully (after lab trials).

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8. Testing of Admixtures and Admixtured Concrete

8.1 Laboratory Tests for Chemical Admixtures

As per **IS 9103:1999**, the following tests are carried out:

- **Setting Time Test:** Using Vicat apparatus.
- **Compressive Strength Test:** 7-day and 28-day strength for treated and untreated samples.
- **Workability Test:** Slump cone or compaction factor.

- **Air Content Test:** Pressure method or gravimetric method.
- **Bleeding Test:** Measured as % water on surface.
- **Compatibility Test:** Marsh cone test or mini-slump test for superplasticizers.

8.2 Tests for Mineral Admixtures

- **Pozzolanic Activity Index (PAI):** As per ASTM C618.
- **Fineness:** Blaine's air permeability or sieve analysis.
- **Specific Surface Area:** BET method (for silica fume).
- **Loss on Ignition (LOI):** Indicates organic matter and unburnt carbon.
- **XRD and SEM:** Identify phase and particle structure.

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9. Practical Guidelines for Use of Admixtures

9.1 General Recommendations

- Always measure admixtures by **mass or volume**, not by guesswork.
- Add admixtures **separately** into the mix water or final stage of mixing.
- Avoid using **expired or contaminated** admixtures.
- Ensure thorough mixing to prevent segregation or non-uniform performance.

9.2 Storage and Handling

- Store admixtures in **cool, dry conditions**, away from direct sunlight.
- Use **clean containers** (plastic or stainless steel preferred).
- Label containers clearly and maintain dosage charts on-site.

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10. Sustainability and Environmental Impact

10.1 Role of Mineral Admixtures in Green Construction

- **Fly ash, GGBS, and silica fume** help reduce cement usage, thereby reducing CO_2 emissions.
- Incorporation of **waste by-products** promotes circular economy principles.

10.2 Carbon Footprint Reduction

- **Each ton of cement replaced** by fly ash or GGBS avoids ~0.9 tons of CO_2 emissions.

- High-volume fly ash concrete (HVFAC) can cut emissions by up to **40%** compared to OPC concrete.

10.3 LEED and GRIHA Ratings

- Use of certified SCMs contributes points in **green building rating systems**.
- Lower embodied energy materials are preferred in sustainable infrastructure.

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11. Recent Developments in Admixture Technology

11.1 Nano-Admixtures

- Use of nano-silica, nano-alumina improves packing density and early strength.
- Still under research but promising for **ultra-high-performance concrete (UHPC)**.

11.2 Self-Healing Admixtures

- Encapsulated bacteria or polymers that release healing agents on cracking.
- Used in smart infrastructure and high-longevity structures.

11.3 Multi-Functional Admixtures

- Some modern admixtures combine functionalities (e.g., superplasticizer + corrosion inhibitor).
- Improves efficiency and simplifies mix design.

11.4 Smart Admixtures

- Responsive to **temperature, pH, or stress**, releasing specific compounds accordingly.
- Still under lab or pilot-scale but rapidly evolving.

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12. Applications of Admixtures in Special Concrete Types

Concrete Type	Admixtures Used
Self-Compacting Concrete (SCC)	Superplasticizer, Viscosity-modifying agents
High-Performance Concrete	Silica fume, superplasticizer, fly ash

Concrete Type	Admixtures Used
Fiber Reinforced Concrete	Water reducer, accelerator, bonding agents
Lightweight Concrete	Air-entraining agents, pumice/expanded aggregates
Mass Concrete	Fly ash, GGBS, retarder
Marine Structures	GGBS, corrosion inhibitor, air-entrainer
Shotcrete	Accelerators, water reducers