Chapter 6: Mineral Admixtures

Introduction

Mineral admixtures are finely divided materials added to concrete to improve its performance in both the fresh and hardened states. These materials are usually by-products from industrial processes and are used to partially replace cement. The use of mineral admixtures is motivated by the need for improved workability, durability, sustainability, and cost-efficiency in concrete. They significantly influence the hydration process, microstructure development, and long-term behavior of concrete.

Mineral admixtures are classified primarily based on their **pozzolanic** or **latent hydraulic** properties. While pozzolans react with calcium hydroxide (CH) in the presence of water to form additional calcium silicate hydrate (C-S-H), latent hydraulic materials, such as Ground Granulated Blast Furnace Slag (GGBS), exhibit cementitious behavior when activated.

6.1 Classification of Mineral Admixtures

Mineral admixtures are broadly classified as:

1. **Pozzolanic Admixtures**
    - Fly ash
    - Silica fume
    - Metakaolin
    - Rice husk ash
2. **Hydraulic Admixtures**
    - Ground Granulated Blast Furnace Slag (GGBS)
    - Natural pozzolans (volcanic tuffs, diatomaceous earth)
3. **Inert Fillers** (used sometimes to control heat of hydration or modify workability)
    - Limestone powder
    - Quartz powder

6.2 Fly Ash (Pulverised Fuel Ash)

Origin and Production

Fly ash is a by-product obtained from the combustion of pulverized coal in thermal power plants. It consists primarily of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and iron oxide (Fe_2O_3).

Types of Fly Ash

- **Class F**: Low in calcium; pozzolanic in nature.
- **Class C**: High in calcium; both pozzolanic and cementitious.

Properties

- Specific surface: 300–500 m^2/kg
- Fineness: Varies with grinding
- Pozzolanic activity: Depends on reactive silica content
- Color: Gray to black

Effects on Concrete

- Improves workability and pumpability
- Reduces water demand
- Enhances long-term strength
- Reduces permeability
- Slower early strength gain
- Reduces heat of hydration

6.3 Silica Fume (Microsilica)

Origin and Production

Silica fume is an ultra-fine by-product obtained from the manufacture of silicon and ferrosilicon alloys in electric arc furnaces.

Properties

- Extremely high surface area: ~20,000 m^2/kg
- Particle size: < 1 µm
- SiO_2 content: > 90%

- Highly reactive pozzolan

Effects on Concrete

- Significantly improves compressive and flexural strength
- Reduces permeability and chloride ion penetration
- Increases cohesiveness and reduces bleeding
- Enhances bond strength with reinforcement
- May increase water demand (requires superplasticizers)

6.4 Ground Granulated Blast Furnace Slag (GGBS)

Origin and Production

GGBS is produced by quenching molten iron slag (a by-product of steel manufacturing) in water or steam, which results in a glassy, granular product that is then dried and ground.

Properties

- Latent hydraulic (requires activation)
- Fineness: Similar or slightly finer than OPC
- Color: Off-white or light gray
- Lower heat of hydration than OPC

Effects on Concrete

- Enhances long-term strength and durability
- Improves resistance to sulfate and chloride attack
- Reduces alkali-silica reaction (ASR)
- Contributes to better finish and appearance
- Slower early strength gain

6.5 Metakaolin

Origin and Production

Metakaolin is obtained by the calcination of purified kaolinite clay at temperatures between 600–800°C, converting it into an amorphous aluminosilicate.

Properties

- Highly reactive pozzolan
- SiO_2 and Al_2O_3 rich
- Specific surface: High (depends on processing)

Effects on Concrete

- Increases early and long-term strength
- Reduces porosity and permeability
- Enhances resistance to ASR
- Improves surface finish
- Effective in high-performance concrete (HPC)

6.6 Rice Husk Ash (RHA)

Origin and Production

RHA is produced by burning rice husks under controlled temperature conditions to retain high amorphous silica content.

Properties

- High SiO_2 content (~85–95%)
- Fine particle size
- Color: Gray to black (depends on burning conditions)

Effects on Concrete

- Reduces water absorption and permeability
- Enhances durability and resistance to aggressive environments
- Increases strength when used in optimum proportion
- Good replacement for silica fume in some cases

6.7 Natural Pozzolans

These include materials such as:

- Volcanic ash (e.g., Santorin earth)
- Diatomaceous earth
- Pumicite

Properties and Effects

- Moderate pozzolanic activity
- Improve long-term durability
- Sustainable and naturally occurring
- Performance depends on fineness and mineral composition

6.8 Influence of Mineral Admixtures on Properties of Concrete

Property	Effect of Mineral Admixtures
Workability	Generally improves due to spherical particles (e.g., fly ash); may require water reducers for silica fume
Strength	Early strength may reduce; long-term strength improves significantly
Durability	Greatly enhanced; lower permeability, higher chemical resistance
Heat of Hydration	Reduced, especially with fly ash and slag
Bleeding and Segregation	Reduced with fine mineral admixtures like silica fume
Alkali-Silica Reaction (ASR)	Reduced with pozzolanic materials
Chloride Penetration	Greatly reduced, improving corrosion resistance

6.9 Factors Affecting Performance of Mineral Admixtures

1. **Fineness**: Finer particles increase reactivity and filler effect.
2. **Replacement level**: Optimal performance depends on appropriate dosage—usually between 5–50% by weight of cement.
3. **Curing conditions**: Adequate moisture and temperature enhance pozzolanic reaction.

4. **Compatibility with admixtures**: Especially important with water reducers and superplasticizers.
5. **Cement chemistry**: Influences the reactivity of mineral admixtures.

6.10 Environmental and Economic Considerations

- **Sustainability**: Reduces cement consumption, thereby lowering CO_2 emissions.
- **Waste Utilization**: Helps utilize industrial waste such as fly ash and slag.
- **Cost Reduction**: Some admixtures (like fly ash) reduce overall material cost.
- **Energy Savings**: Less energy-intensive than Portland cement production.

6.11 Applications in Special Concretes

- **High-Performance Concrete (HPC)**: Uses silica fume, metakaolin.
- **Mass Concrete**: Fly ash and slag are used to control heat of hydration.
- **Marine Structures**: Mineral admixtures reduce permeability and chloride ingress.
- **Precast Concrete**: Silica fume enhances strength and surface finish.
- **Self-Compacting Concrete (SCC)**: Uses fly ash, slag, and silica fume to improve flowability and stability.

Certainly! Continuing from **Section 6.11**, here's **additional in-depth content** to extend Chapter 6 further for your e-book on *Concrete Technology (BTech Civil Engineering)*:

6.12 Hydration Reactions of Mineral Admixtures

Pozzolanic Reaction Mechanism

Most mineral admixtures undergo a secondary hydration process known as **pozzolanic reaction**, where they react with calcium hydroxide ($Ca(OH)_2$)—a by-product of cement hydration—to form additional calcium silicate hydrate (C-S-H), the main strength-giving compound in concrete.

Basic Reaction (Simplified): $SiO_2 + Ca(OH)_2 + H_2O \rightarrow \text{C-S-H}$

Impact on Microstructure

- **Refinement of pore structure**: Leads to lower permeability and higher density.
- **Reduction in $Ca(OH)_2$ crystals**: Minimizes leaching and efflorescence.
- **Increased volume of C-S-H gel**: Improves long-term strength and durability.

Hydraulic Reaction (GGBS)

In the presence of water and alkaline activators (like calcium hydroxide from OPC), GGBS undergoes hydration similar to Portland cement, forming:

$$\text{GGBS} + H_2O \rightarrow \text{C-S-H} + \text{C-A-H}(calcium aluminate hydrates)$$

6.13 Compatibility with Chemical Admixtures

Mineral admixtures interact with chemical admixtures such as superplasticizers, retarders, and air-entraining agents. Their influence varies depending on the type and dosage of both mineral and chemical admixtures.

Key Compatibility Issues

- **Silica Fume** may increase water demand—superplasticizers are often necessary.
- **Fly Ash** delays setting time—can interact with retarders.
- **Metakaolin** increases thixotropy and may reduce flow—superplasticizers improve workability.
- **GGBS** is generally compatible but may affect setting in cold climates.

6.14 Testing and Quality Control of Mineral Admixtures

Standards Followed

- **IS 3812** – For Fly Ash
- **IS 15388** – For Silica Fume
- **IS 12089** – For GGBS
- **ASTM C618** – For Fly Ash and Natural Pozzolans
- **BS EN 15167** – For GGBS

Key Tests Conducted

Test Name	Purpose
Fineness (Blaine method)	Reactivity & blending efficiency
Pozzolanic Activity Index	Strength gain capability
Loss on Ignition (LOI)	Indicates unburnt carbon (in fly ash)
Chemical Analysis (XRF)	Determines SiO_2, Al_2O_3, Fe_2O_3, CaO
Specific Gravity	Affects mix design calculations
Soundness (Le Chatelier)	Stability in volume change

6.15 Guidelines for Mix Design with Mineral Admixtures

Replacement Levels (Typical Ranges)

Admixture	Cement Replacement (%)
Fly Ash	15–35% (up to 50% for mass concrete)
Silica Fume	5–10%
GGBS	30–70%
Metakaolin	5–15%
Rice Husk Ash	5–15%

Key Considerations

- **Water-Cementitious Ratio (w/cm)**: Should be adjusted based on fineness and absorption.
- **Curing Duration**: Longer curing improves pozzolanic benefits.
- **Workability**: May need admixtures to achieve desired slump.
- **Setting Time**: Extended with fly ash or GGBS; accelerated with metakaolin.

6.16 Advantages of Using Mineral Admixtures

Technical Benefits

- Enhanced strength and durability
- Reduced permeability and shrinkage

- Better surface finish and cohesiveness
- Improved resistance to chemical attack and corrosion

Economic Benefits

- Reduction in cement usage
- Cost-effective solutions using industrial by-products
- Improved lifecycle performance and serviceability

Environmental Benefits

- Reduced CO_2 emissions (less clinker production)
- Recycling of industrial waste materials
- Lower energy consumption in manufacturing

6.17 Challenges and Limitations

- **Variability in Composition**: Especially in fly ash and rice husk ash
- **Slower Strength Gain**: Needs adjustments in construction scheduling
- **Availability and Transportation**: Especially for materials like silica fume
- **Increased Quality Control**: More testing and monitoring required
- **Compatibility with Cement and Admixtures**: Needs pre-trials in most projects

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6.18 Innovations and Research Trends

Nano-Mineral Admixtures

- **Nano-silica**: Enhances early strength and microstructure
- **Nano-metakaolin**: Improves packing density and pozzolanic activity

Hybrid Blended Systems

- Combining multiple mineral admixtures (e.g., Fly Ash + Silica Fume)
- Tailoring mix designs for ultra-high performance concrete (UHPC)

Self-Healing Concrete

- Some admixtures help promote autogenous healing by refining pore structure

Alkali-Activated Binders

- Fly ash and GGBS used in **Geopolymer Concrete**, reducing reliance on OPC