Chapter 2: Ingredients of Concrete

Introduction

Concrete is one of the most widely used construction materials in the world due to its versatility, durability, and economic viability. The performance and properties of concrete depend significantly on its ingredients and the way they interact during mixing, placing, curing, and hardening. A thorough understanding of the ingredients of concrete is crucial for civil engineers to design, produce, and evaluate high-quality concrete suited for specific applications.

Concrete is essentially a composite material composed of the following primary ingredients:

- **Cement**
- **Aggregates (Fine and Coarse)**
- **Water**
- **Admixtures** (optional but often necessary)

Each ingredient plays a distinct and interrelated role in defining the fresh and hardened properties of concrete.

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1. Cement

Cement is the binding material that binds the other ingredients together upon hydration. The most commonly used type of cement in concrete is **Ordinary Portland Cement (OPC)**.

1.1 Chemical Composition of Cement

The primary chemical compounds found in Portland cement are:

Compound	Abbreviation	Approximate %	Role
Tricalcium Silicate	C_3S	40–60%	Provides early strength
Dicalcium Silicate	C_2S	15–30%	Provides long-term strength
Tricalcium	C_3A	5–12%	Influences

Compound	Abbreviation	Approximate %	Role
Aluminate			setting time, heat of hydration
Tetracalcium Aluminoferrite	C_4AF	6–10%	Provides color and reduces cost

Other minor compounds include alkalis, magnesium oxide, and gypsum (added to control the setting time).

1.2 Heat of Hydration

When cement reacts with water, an exothermic chemical reaction known as **hydration** occurs, releasing heat. This is called the **heat of hydration**.

- **C_3A** and **C_3S** contribute most to the early heat generation.
- High heat of hydration can lead to cracking in massive concrete structures unless controlled by cooling techniques or slow-setting cements.

1.3 Structure of Hydrated Cement

The hydration products include:

- **Calcium Silicate Hydrate (C-S-H)**: Responsible for strength.
- **Calcium Hydroxide (CH)**: Byproduct, contributes little to strength.
- **Ettringite**: Forms from C_3A and gypsum; affects setting and early strength.
- **Monosulfate**: Forms after ettringite transformation in later stages.

1.4 Physical Tests on Cement

To ensure quality and suitability for construction, the following tests are performed on cement:

- **Fineness test** (e.g., Blaine's air permeability method)
- **Standard consistency test**
- **Initial and final setting time**
- **Compressive strength of cement mortar cubes**
- **Soundness test** (e.g., Le-Chatelier method)
- **Specific gravity test**

2. Aggregates

Aggregates occupy about 70–80% of the volume of concrete and significantly influence its strength, workability, and durability.

2.1 Classification of Aggregates

Based on Size

- **Fine Aggregates**: Usually natural sand or crushed stone passing through 4.75 mm IS sieve.
- **Coarse Aggregates**: Retained on 4.75 mm IS sieve. Sizes range from 10 mm to 40 mm for general construction.

Based on Source

- **Natural Aggregates**: Obtained from riverbeds, pits, and quarries.
- **Artificial Aggregates**: Manufactured aggregates like blast furnace slag, lightweight expanded clay, etc.
- **Recycled Aggregates**: Derived from demolished concrete structures.

Based on Density

- **Normal weight aggregates**
- **Lightweight aggregates** (e.g., pumice, expanded perlite)
- **Heavyweight aggregates** (e.g., barite, hematite—for radiation shielding)

2.2 Properties of Aggregates

- **Shape**: Angular, rounded, flaky, or elongated. Rounded particles increase workability, angular increase strength.
- **Texture**: Smooth or rough; rough surfaces create better bonding with cement paste.
- **Specific Gravity**: Ranges from 2.4 to 2.9 for most natural aggregates.
- **Water Absorption**: Influences water-cement ratio.
- **Bulk Density**: Important for mix design.
- **Moisture Content**: Free surface moisture and absorption capacity must be considered.
- **Strength**: Crushing strength impacts the final compressive strength of concrete.
- **Durability**: Aggregates should be chemically inert and resistant to environmental degradation.

2.3 Grading of Aggregates

Grading refers to the particle size distribution in aggregates. Proper grading ensures:

- Minimum voids
- Maximum density
- Good workability and strength

Fine Aggregate Grading Zones (IS 383)

- Zone I: Coarse
- Zone II: Medium
- Zone III: Fine
- Zone IV: Very fine

2.4 Methods of Combining Aggregates

To obtain the desired grading, different sizes of aggregates are proportioned:

- **Trial-and-error method**
- **Graphical methods** like Fineness Modulus Method
- **Particle size distribution curve adjustment**

2.5 Testing of Aggregates

- **Sieve Analysis** (for grading)
- **Specific Gravity and Water Absorption**
- **Aggregate Impact Value (AIV)**
- **Aggregate Crushing Value (ACV)**
- **Los Angeles Abrasion Test**
- **Soundness Test**
- **Alkali-Silica Reactivity Test**

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3. Water

Water initiates the chemical reaction with cement (hydration) and is essential for workability and compaction.

3.1 Requirements of Mixing Water

- **Potable water** is generally suitable.

- Must be **free from impurities** like oils, acids, alkalis, salts, organic matter, and sugar.
- **pH value** should be ≥ 6.

3.2 Functions of Water

- Hydrates the cement
- Provides workability
- Dissolves admixtures and facilitates uniform distribution

3.3 Water-Cement Ratio (w/c Ratio)

- Crucial factor in determining strength and durability.
- Lower w/c = higher strength and durability but lower workability.
- Typical range: **0.4–0.6** (by weight).

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4. Admixtures

Admixtures are added to concrete in small quantities (less than 5% of cement weight) to alter or enhance specific properties.

4.1 Types of Admixtures

Type	Function
Plasticizers	Increase workability without extra water
Superplasticizers	Provide high workability and strength
Accelerators	Speed up setting and early strength gain
Retarders	Delay setting time
Air-Entraining Agents	Introduce microscopic air bubbles for freeze-thaw resistance
Water-Reducing Agents	Reduce water requirement at constant workability
Pozzolanic Materials	Improve long-term strength and durability
Corrosion Inhibitors	Reduce reinforcement corrosion

Type	Function
	in concrete

4.2 Common Admixture Materials

- **Fly ash**
- **Silica fume**
- **Ground granulated blast furnace slag (GGBFS)**
- **Metakaolin**
- **Lignosulphonates**
- **Polycarboxylate ethers (PCE)**

4.3 Compatibility with Cement

Not all admixtures are universally compatible with every type of cement. Proper testing is needed before use in construction, especially when using blended or specialty cements.

4.4 Selection of Admixtures – Practical Considerations

Choosing the correct admixture depends on various project-specific parameters such as:

- **Environmental conditions** (temperature, humidity)
- **Construction speed**
- **Type of structure** (e.g., bridge decks, dams, pavement)
- **Transportation time** (for Ready Mix Concrete)
- **Durability requirements** (marine, chemical exposure)

Examples:

- Use **retarders** in hot weather concreting to prevent flash setting.
- Use **superplasticizers** for pumping concrete over long distances or into heavily congested reinforcement zones.
- Use **air-entraining agents** in freeze–thaw environments like high altitudes or cold regions.

4.5 Effects of Admixtures on Fresh and Hardened Concrete Properties

Property	Influence of Admixtures
Workability	Plasticizers and superplasticizers greatly improve flow.
Setting Time	Accelerators decrease, retarders increase.
Strength Development	Some admixtures (e.g., silica fume, fly ash) enhance later-age strength.
Durability	Air-entrainment improves freeze–thaw resistance; pozzolans reduce permeability.
Shrinkage and Creep	Some admixtures reduce drying shrinkage and long-term deformation.
Water Demand	Reduced by superplasticizers without affecting workability.

4.6 Advances in Chemical Admixtures

Modern admixtures are increasingly sophisticated and tailored to complex construction challenges. Some notable types include:

1. Polycarboxylate Ether (PCE) Based Superplasticizers

- Provide superior dispersion with low dosages.
- Allow production of **self-compacting concrete (SCC)**.
- Reduce w/c ratio to as low as 0.25 while maintaining flowability.

2. Shrinkage-Reducing Admixtures (SRA)

- Minimize shrinkage cracking by lowering surface tension of pore water.
- Useful in industrial floors, bridge decks, and water tanks.

3. Hydration-Control Admixtures

- Allow **extended workability periods** up to 72 hours.
- Used in **long-haul RMC**, mass concreting, or emergency stoppage situations.

4. Corrosion Inhibitors

- Typically calcium nitrite-based.
- Protect reinforcing steel in aggressive environments (marine, deicing salts).

5. Crystalline Waterproofing Admixtures

- React with moisture and cement particles to form insoluble crystals.
- Seal micro-cracks and capillaries.
- Useful in basements, tunnels, water-retaining structures.

4.7 Mineral Admixtures (Supplementary Cementitious Materials - SCMs)

These are **powdered materials** added to improve strength, durability, and sustainability.

Types of SCMs

SCM	Source	Main Benefit
Fly Ash (Class F & C)	Coal combustion	Improves long-term strength and workability
Silica Fume	Silicon/ferrosilicon industry	Fills pores, increases strength and impermeability
GGBFS	Blast furnaces	Reduces heat of hydration and enhances durability
Rice Husk Ash	Agricultural waste	Pozzolanic and eco-friendly
Metakaolin	Calcined clay	Increases early strength and resistance to alkali-silica reaction

Blended Cement Types (as per IS 455, IS 1489, etc.)

- Portland Pozzolana Cement (PPC)
- Portland Slag Cement (PSC)
- Composite Cements

4.8 Environmental Considerations and Sustainable Concrete

Carbon Footprint of Ingredients

- Cement production contributes ~7–8% of global CO_2 emissions.
- Reducing clinker content using SCMs lowers emissions significantly.

Green Concrete Initiatives

- Use of industrial by-products (fly ash, GGBFS)
- Recycled aggregates
- Bio-based admixtures
- CO_2-injected concrete (carbon curing technologies)

Life Cycle Assessment (LCA) of Ingredients

A full LCA includes:

- Raw material extraction
- Processing energy
- Transportation emissions
- Durability and service life

Example: Replacing 30% cement with fly ash can lower embodied CO_2 by 25–30% per cubic metre of concrete.

4.9 Tests on Concrete Ingredients as per Indian Standards

Ingredient	Test	IS Code
Cement	Fineness, Consistency, Setting Time, Strength	IS 4031
Fine Aggregates	Sieve Analysis, Specific Gravity, Bulking	IS 2386 (Part I-VIII)
Coarse Aggregates	Crushing, Impact, Abrasion, Flakiness	IS 2386
Water	pH, Solids, Organic Impurities	IS 3025
Admixtures	Compatibility, Performance in Mix	IS 9103

4.10 Storage and Handling of Ingredients

Proper storage and handling are vital to ensure consistency and avoid contamination.

Cement

- Stored in dry, leakproof silos or raised platform sheds.
- Use FIFO (First-In-First-Out) principle to avoid expiry.

Aggregates

- Stored on hard, clean platforms.
- Different sizes separated using barriers.
- Avoid exposure to organic matter or mud.

Water

- Source tested regularly.
- Avoid using water with high sulfates, chlorides, or suspended solids.

Admixtures

- Stored in sealed containers, protected from heat and direct sunlight.
- Must be stirred before use if they are in suspension or emulsion form.
