

Chapter 24: Special Concrete and Concreting Methods – Lightweight and High-Strength Concrete

Introduction

In modern civil engineering, the demand for concrete with specialized properties has significantly increased due to the diverse requirements of construction projects. Among these, *Lightweight Concrete (LWC)* and *High-Strength Concrete (HSC)* stand out as two widely adopted innovations. These concrete types are engineered for specific performance characteristics such as reduced density, high compressive strength, thermal insulation, and improved durability. This chapter explores their composition, properties, methods of production, applications, and testing in detail.

1. Lightweight Concrete (LWC)

1.1 Definition

Lightweight concrete is a type of concrete with a lower density than conventional concrete, typically ranging between **800–2000 kg/m³**, achieved by replacing dense aggregates with lightweight ones or incorporating air voids.

1.2 Types of Lightweight Concrete

1. Lightweight Aggregate Concrete

- o Uses lightweight aggregates like **expanded clay, shale, pumice, vermiculite**, or **perlite**.
- o Common in structural and non-structural applications.

2. Aerated or Foamed Concrete

- o Contains uniformly distributed air bubbles created by chemical agents (e.g., aluminum powder).
- o Density: **300–1200 kg/m³**.
- o Often used in blocks, panels, and insulation.

3. No-Fines Concrete

- o Produced without fine aggregates.
- o Coarse aggregates are bound by a cement slurry.
- o Porous and permeable, suitable for drainage and thermal insulation.

1.3 Properties of Lightweight Concrete

- **Lower Density:** Reduces dead load on structures.
- **Thermal Insulation:** Effective in controlling heat transfer.
- **Fire Resistance:** Excellent resistance due to porous structure.
- **Workability:** Depends on the type of lightweight aggregate used.
- **Compressive Strength:** Typically ranges from **5 to 40 MPa**, depending on application.

1.4 Materials Used

- **Cement:** Ordinary Portland Cement (OPC) or blended cement.
- **Lightweight Aggregates:** Expanded clay, pumice, perlite, etc.
- **Water:** Potable water; water-cement ratio is controlled.
- **Admixtures:** Water-reducing agents, foaming agents, air-entraining agents.

1.5 Mixing and Placement

- Lightweight aggregates often require **pre-wetting** to prevent excessive absorption of mixing water.
- Mix design must be adjusted for **volume replacement** instead of weight replacement.
- Proper **vibration and compaction** are essential to prevent segregation.

1.6 Applications of Lightweight Concrete

- **High-rise buildings** to reduce dead loads.
 - **Bridge decks** and **precast elements**.
 - **Thermal insulation panels** and **roof slabs**.
 - **Seismic zones** for reduced structural mass.
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2. High-Strength Concrete (HSC)

2.1 Definition

High-strength concrete is defined as concrete with a **compressive strength exceeding 60 MPa**. In modern projects, it may range up to **100–150 MPa**, achieved through optimized mix designs and advanced materials.

2.2 Need for High-Strength Concrete

- To **reduce cross-sectional dimensions** of structural elements.
- For **high-rise buildings, long-span bridges, offshore structures**, and **nuclear plants**.
- To **improve durability and performance** in aggressive environments.

2.3 Materials Used

1. **Cement:**
 - o OPC Grade 53 or blended cement with silica fume or slag.
2. **Fine Aggregates:**
 - o Well-graded natural or manufactured sand.
3. **Coarse Aggregates:**
 - o Crushed stone with controlled shape and grading.
 - o Max size usually 10–20 mm for better packing.
4. **Supplementary Cementitious Materials (SCMs):**
 - o **Silica fume, fly ash, GGBS (Ground Granulated Blast Furnace Slag).**
 - o Improve **particle packing** and **strength gain**.
5. **Chemical Admixtures:**
 - o **High-range water reducers (superplasticizers).**
 - o Retarders or accelerators as required.
6. **Water:**
 - o Low **water-cement ratio** (~0.25–0.35) essential for high strength.

2.4 Properties of High-Strength Concrete

- **Compressive Strength:** >60 MPa, can exceed 100 MPa.
- **Low Water Permeability:** Due to dense microstructure.
- **High Durability:** Resistant to carbonation, chloride ingress, and sulfate attack.
- **Brittleness:** Often more brittle than normal concrete; steel fibers or polymer additions are used to improve ductility.
- **Shrinkage and Creep:** Higher due to low w/c ratio; requires proper curing.

2.5 Mix Design Considerations

- **Aggregate packing density** is critical.

- Use of **micro-fillers** like silica fume enhances particle size distribution.
- Requires **precise control** over mixing, batching, and curing.
- Often designed using **trial mixes** and performance-based specifications.

2.6 Production and Concreting Methods

- **Ready-Mix Concrete (RMC)** plants preferred for controlled batching.
- **High-performance mixers** used to ensure uniformity.
- Use of **pumping techniques** due to stiff mixes.
- **Steam curing** or **accelerated curing** methods adopted for precast units.

2.7 Applications of High-Strength Concrete

- **Skyscrapers** (e.g., Burj Khalifa used 80+ MPa concrete).
 - **Nuclear containment structures.**
 - **Prestressed concrete bridges.**
 - **Offshore oil rigs, high-load columns, industrial floors.**
 - **Architectural structures** requiring slim and elegant profiles.
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3. Comparison: Lightweight vs High-Strength Concrete

Property	Lightweight Concrete	High-Strength Concrete
Density (kg/m ³)	800–2000	2200–2500+
Compressive Strength	5–40 MPa	>60 MPa (can go up to 150 MPa)
Thermal Insulation	Excellent	Moderate to poor
Cost	Moderate to High	High
Durability	Moderate	Very High
Typical Use	Roof slabs, panels, seismic zones	Skyscrapers, bridges, nuclear plants

4. Testing and Quality Control

4.1 For Lightweight Concrete

- **Density Test** (IS 2386 Part III)
- **Compressive Strength** (IS 516)

- **Slump Test** (IS 1199)
- **Thermal Conductivity Test**
- **Moisture Absorption Test**

4.2 For High-Strength Concrete

- **Compressive Strength** (IS 516)
 - **Flexural Strength**
 - **Ultrasonic Pulse Velocity (UPV)**
 - **Chloride Penetration Test (RCPT)**
 - **Modulus of Elasticity**
 - **Shrinkage & Creep Testing**
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5. Challenges in Practice

- **Lightweight Concrete:**
 - Control over water absorption of aggregates.
 - Ensuring uniform air entrainment.
 - Lower mechanical strength for structural applications.
 - **High-Strength Concrete:**
 - Workability issues due to low w/c ratio.
 - Risk of thermal cracking due to high cement content.
 - Need for skilled handling, curing, and quality control.
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7. Innovations and Recent Advances

7.1 Fiber-Reinforced Lightweight Concrete

To improve the **tensile strength and ductility** of lightweight concrete, fibers such as:

- **Glass fibers**
- **Polypropylene fibers**
- **Steel fibers**
- **Carbon fibers**

are incorporated. These fibers help:

- Control **crack propagation**
- Improve **post-crack behavior**
- Enhance **impact resistance**

7.2 High-Strength Self-Compacting Concrete (HS-SCC)

A revolutionary development where:

- The concrete has **high flowability**
- No need for **vibration** during placement
- Achieves strength >80 MPa

It is ideal for:

- Congested reinforcement zones
- Precast industries
- Complex formwork sections

Admixture system: A combination of **superplasticizers**, **viscosity modifying agents (VMAs)**, and **pozzolans**.

7.3 Nano-Technology in High-Strength Concrete

The use of:

- **Nano-silica**
- **Carbon nanotubes (CNTs)**
- **Graphene oxide**

Improves:

- **Microstructure** densification
 - **Hydration process** refinement
 - **Compressive and tensile strength** by controlling nanoscale porosity
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8. Environmental and Sustainability Considerations

8.1 Carbon Footprint of High-Strength Concrete

- Higher cement content means **higher CO₂ emissions**.
- Strategies to reduce:
 - Use **supplementary cementitious materials (SCMs)**

- o Optimize **cement efficiency**
- o Use **alternative binders** (e.g., geopolymers)

8.2 Sustainable Lightweight Aggregates

Produced from:

- **Industrial by-products** (e.g., fly ash, blast furnace slag)
- **Recycled concrete aggregate (RCA)**
- **Expanded polystyrene (EPS) beads**

Advantages:

- Reduces **waste disposal**
- Promotes **circular economy**
- Enhances **thermal and acoustic insulation**

8.3 Water Usage Efficiency

- Use of **recycled water** in mixing.
 - Use of **low w/c ratio** and **moisture-retaining aggregates**.
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9. Case Studies and Applications

9.1 Lightweight Concrete in Burj Al Arab, Dubai

- Used **aerated concrete panels** for non-structural walls.
- Reduced **overall dead load** by ~15%.
- Improved **thermal insulation** due to UAE's harsh climate.

9.2 High-Strength Concrete in Burj Khalifa, Dubai

- C80 and C100 concrete grades used.
- Concrete pumped vertically to **over 600 meters**.
- Required special **retarders** and **high-performance superplasticizers**.
- Mass concrete pours managed using **thermal control systems**.

9.3 Seismic Applications in Japan and California

- Use of **Lightweight Aggregate Concrete (LWAC)** in multi-storey buildings.
 - Reduced seismic force due to **mass reduction**.
 - Combinations with **damping systems** for improved performance.
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10. Future Trends and Research Areas

10.1 3D Printing with Special Concrete

- Requires **flowable, fast-setting mixes**.
- Ongoing research into **lightweight 3D printable concrete**.
- Potential for rapid housing, especially in disaster-prone or rural areas.

10.2 Self-Healing High-Strength Concrete

- Embedding **bacteria or capsules** that release healing agents when cracks form.
- Restores **durability and strength** without external maintenance.

10.3 Smart Concrete

- Embedded **sensors** (e.g., piezoelectric, fiber optic) for:
 - Monitoring stress, temperature, corrosion
 - Real-time **structural health monitoring (SHM)**

10.4 Use of AI in Concrete Mix Design

- AI and **machine learning** algorithms to predict:
 - **Optimal mix proportions**
 - **Strength gain curves**
 - **Durability performance** under variable conditions
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