

Chapter 13: High Performance Concrete (HPC)

Introduction

Concrete, as the most widely used construction material, has undergone significant innovation to meet the growing demands for durability, strength, and sustainability. In this context, **High Performance Concrete (HPC)** has emerged as a remarkable advancement. Unlike conventional concrete, HPC is designed to have specific properties such as high strength, superior durability, enhanced workability, reduced permeability, and extended service life.

High Performance Concrete is not defined by a specific compressive strength threshold alone but rather by a combination of desirable properties that make it suitable for critical infrastructure projects, long-span bridges, marine structures, nuclear power plants, and high-rise buildings.

1. Characteristics of High Performance Concrete

High Performance Concrete possesses several distinguishing characteristics, including:

a) High Strength

- Typically exceeds 60 MPa at 28 days.
- Can go up to 100 MPa or more depending on design and curing conditions.

b) High Durability

- Resistant to chemical attacks, freeze-thaw cycles, abrasion, and alkali-silica reaction.
- Low chloride and water permeability.

c) Improved Workability

- Achieved through superplasticizers and viscosity-modifying admixtures.
- Suitable for complex formwork and densely reinforced areas.

d) Reduced Permeability

- Dense matrix structure minimizes water and gas ingress, enhancing the life of the structure.

e) Early Age Strength Gain

- Essential in precast industries and fast-track construction projects.
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2. Materials for High Performance Concrete

The quality of HPC heavily depends on the selection and proportioning of its ingredients.

a) Cement

- Ordinary Portland Cement (OPC) Grade 53 is commonly used.
- Blended cements like Portland Pozzolana Cement (PPC) may be used with supplementary materials.

b) Supplementary Cementitious Materials (SCMs)

- **Silica Fume:** Enhances strength and reduces permeability.
- **Fly Ash:** Improves workability and long-term strength.
- **Ground Granulated Blast Furnace Slag (GGBS):** Enhances durability and workability.
- **Metakaolin:** Increases early strength and reduces shrinkage.

c) Aggregates

- Well-graded coarse and fine aggregates.
- Maximum size of coarse aggregate is generally limited to 20 mm for better compaction.

d) Chemical Admixtures

- **Superplasticizers** (Polycarboxylate Ether – PCE based): Increase workability without extra water.
- **Retarders and Accelerators:** Control setting time based on project requirement.
- **Shrinkage-reducing admixtures:** To minimize autogenous and drying shrinkage.

e) Water

- Potable water with low impurities.

f) Fibers (Optional)

- Steel, polypropylene, or glass fibers may be added for improved toughness and crack resistance.

3. Mix Design for High Performance Concrete

Mix design for HPC is more intricate than conventional concrete and follows principles ensuring both strength and durability:

a) Water-Cement Ratio

- Very low, typically between **0.25 to 0.35**, to limit porosity.
- Requires high-range water reducers to maintain workability.

b) Aggregate Packing

- Optimum gradation to reduce voids and paste requirement.
- Use of fine fillers such as micro-silica to fill voids.

c) Paste Content

- Adequate paste content to ensure good workability and avoid segregation.

d) Trial Mixes

- Extensive trials and testing are needed to optimize performance for field conditions.
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4. Properties of High Performance Concrete

a) Fresh State Properties

- **Workability:** High slump (150–230 mm), self-consolidating with minimal segregation.
- **Setting Time:** Controlled with admixtures.

b) Hardened State Properties

- **Compressive Strength:** Usually greater than 60 MPa at 28 days.
 - **Modulus of Elasticity:** Higher than conventional concrete.
 - **Shrinkage and Creep:** Lower but requires attention due to dense matrix.
 - **Permeability:** Very low, enhancing resistance to aggressive environments.
 - **Durability:** Excellent performance in harsh conditions including sulfate-rich soils, marine, and freezing environments.
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5. Curing of High Performance Concrete

Proper curing is crucial for achieving the designed properties:

a) Curing Methods

- **Steam Curing:** For precast and early strength.
- **Water Curing:** Common but must be prolonged.
- **Curing Compounds:** Useful in remote or large surface areas.

b) Curing Duration

- Longer than conventional concrete due to low water-binder ratio.
 - At least **14 days** of moist curing recommended for silica fume concrete.
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6. Applications of High Performance Concrete

HPC finds its place in several demanding applications due to its superior properties:

- **Long-span bridges** (e.g., prestressed girders and decks)
 - **High-rise buildings** (requiring strength and reduced cross-sectional elements)
 - **Marine and coastal structures** (due to low permeability)
 - **Nuclear containment structures**
 - **Tunnel linings**
 - **Industrial floors and pavements**
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7. Differences Between HPC and Conventional Concrete

Property	Conventional Concrete	High Performance Concrete
Compressive Strength	20–50 MPa	60–120 MPa or more
Water-Cement Ratio	0.4–0.6	0.25–0.35
Permeability	Moderate to High	Very Low
Durability	Moderate	Excellent
Admixture Use	Limited	Extensive
Workability	Low to Medium	High to Very High
Service Life	30–50 years	75–100+ years

8. Challenges in High Performance Concrete

Despite its advantages, HPC has its own set of limitations:

a) Cost

- Higher initial cost due to use of silica fume, superplasticizers, and high-quality materials.

b) Quality Control

- Requires strict supervision and quality control at every stage (mixing, transporting, placing, curing).

c) Temperature Sensitivity

- Rapid hydration may lead to thermal cracking if not properly managed.

d) Shrinkage and Cracking

- Though reduced, the potential for early-age shrinkage and cracking still exists, requiring careful curing and mix design.
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9. Future Trends in HPC

- **Self-Healing HPC:** Embedded materials to seal cracks autonomously.
 - **Nano-Modified HPC:** Use of nanomaterials like nano-silica for performance enhancement.
 - **Carbon-neutral HPC:** Incorporation of recycled aggregates and carbon capture technologies.
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10. Testing of High Performance Concrete

Comprehensive testing is critical to evaluate the properties and performance of HPC. The tests span across **fresh**, **hardened**, and **durability-related** parameters.

a) Fresh Concrete Tests

- **Slump Flow Test** (ASTM C1611): Measures flowability for self-compacting HPC.
- **V-Funnel Test:** Measures viscosity and segregation resistance.
- **L-Box Test:** Determines passing ability through congested reinforcement.

b) Hardened Concrete Tests

- **Compressive Strength Test** (IS 516): Typically performed at 3, 7, 28, and 90 days.
- **Split Tensile Strength**: Measures tensile resistance, important in cracking analysis.
- **Flexural Strength (Modulus of Rupture)**: For pavement and slab applications.

c) Durability Tests

- **Rapid Chloride Penetration Test (RCPT)**: Measures permeability and chloride ingress.
 - **Water Absorption and Sorptivity Tests**: Evaluate capillary suction and long-term water ingress.
 - **Accelerated Carbonation Test**: To assess resistance to carbonation-induced corrosion.
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11. Case Studies of HPC Applications

a) Petronas Towers, Malaysia

- High-rise building constructed using HPC of 80 MPa compressive strength.
- Enhanced pumpability and flow were achieved using silica fume and PCE admixtures.

b) Bandra-Worli Sea Link, Mumbai

- Used marine-grade HPC for durability against salt spray, high winds, and tides.
- Fiber reinforcement and corrosion-inhibiting admixtures were incorporated.

c) Burj Khalifa, UAE

- Utilized concrete with strengths exceeding 80 MPa pumped to heights above 600 meters.
 - Controlled hydration temperature and shrinkage were critical for success.
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12. Sustainability and Environmental Considerations

Although HPC uses energy-intensive materials like silica fume and cement, it contributes to sustainability in several ways:

a) **Extended Service Life**

- Reduces frequency of repairs and replacements, lowering life-cycle cost and resource use.

b) **Lower Carbon Footprint**

- HPC mixes often use **supplementary cementitious materials (SCMs)** like fly ash and GGBS, reducing reliance on clinker.

c) **Material Efficiency**

- Thinner sections and longer spans reduce overall material consumption.

d) **Water Conservation**

- Low water-cement ratios help conserve water, especially when paired with curing compounds.
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13. Innovations in HPC

a) **Ultra-High Performance Concrete (UHPC)**

- Strength >150 MPa.
- Contains steel or polymer fibers.
- Used in architectural panels, defense structures, and crash barriers.

b) **Self-Compacting High Performance Concrete (SCHPC)**

- Eliminates the need for vibration during placement.
- Ideal for inaccessible or congested reinforcement zones.

c) **Nano-HPC**

- Incorporation of **nano-silica**, **carbon nanotubes**, and **graphene oxide** to enhance early strength and crack resistance.

d) **Bio-based HPC**

- Uses microbial agents to **self-heal** micro-cracks, improving durability naturally.
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14. Economic and Practical Considerations

Despite its higher initial cost, HPC can offer long-term savings.

Aspect	Traditional Concrete	High Performance Concrete
Initial Cost	Lower	Higher
Maintenance	Frequent	Minimal
Life Cycle	30–50 years	75–100+ years
Structural Efficiency	Moderate	High
Cement Usage	Higher	Lower (due to SCMs and fillers)

Important Practical Points:

- Careful **temperature and curing control** is required to avoid thermal stresses.
- **Mix consistency** must be ensured across batches to maintain performance.
- **On-site quality control** must be stricter due to narrow margins for error.

15. Role of HPC in Modern Infrastructure

High Performance Concrete is now seen as a strategic material in civil infrastructure:

- **Smart Cities:** For long-lasting and eco-efficient urban infrastructure.
- **Disaster-Resilient Structures:** For earthquake, hurricane, and fire resistance.
- **Green Construction:** Meets LEED and IGBC sustainability benchmarks.

Governments and agencies are increasingly incorporating HPC into building codes and public infrastructure standards due to its long-term benefits.