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Sustainable High Performance Concrete: Materials, Durability and Environmental Impact – A Review

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ABSTRACT
High Performance Concrete (HPC) has emerged as a major advancement in modern construction due to its superior mechanical strength, durability, and reduced permeability. Sustainable approaches in HPC focus on incorporating supplementary cementitious materials, optimizing mix proportions, and reducing carbon footprint. This review critically examines developments in sustainable HPC, durability performance, mechanical behavior, and environmental benefits reported in literature up to May 2016.
Keywords: *High Performance Concrete, Sustainability, Durability, Fly Ash, Silica Fume, Carbon Emission*

I. INTRODUCTION

High Performance Concrete (HPC) differs from conventional concrete due to its improved strength, durability, and workability characteristics. With increasing infrastructure demands and environmental concerns, sustainable HPC has gained research attention.

II. MATERIALS FOR SUSTAINABLE HPC

Sustainable HPC incorporates supplementary cementitious materials such as fly ash, silica fume, and ground granulated blast furnace slag (GGBS). These materials reduce cement consumption and enhance long-term durability.

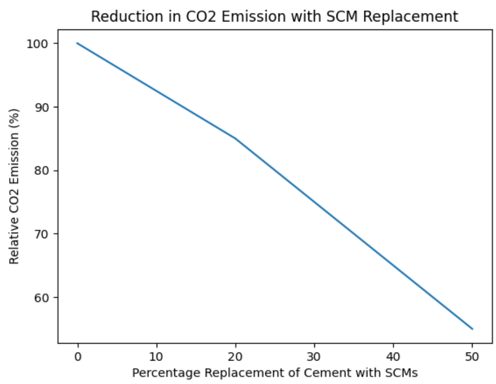
2.1 Fly Ash

Fly ash improves workability and long-term strength due to pozzolanic reactions. It also reduces heat of hydration and permeability.

2.2 Silica Fume

Silica fume enhances microstructure by filling voids and producing additional C-S-H gel, leading to high compressive strength and low permeability.

Chart 1: Reduction in CO2 Emission with SCM Replacement



III. MECHANICAL PROPERTIES OF HPC

HPC typically exhibits compressive strength above 60 MPa. Low water-binder ratio and optimized particle packing contribute to improved performance.

1. Compressive Strength

- Primary property of HPC.
- Much higher than normal concrete.
- Typical range: **60–120 MPa**
  (can exceed 150 MPa in UHPC).

Reasons for high strength:

- Low w/b ratio (0.20–0.35)
- Silica fume & pozzolans → more C–S–H
- Reduced capillary pores
- Strong ITZ (interfacial transition zone)

Behavior:

- More brittle than normal concrete
- Steeper stress–strain curve
- Higher peak stress

2. Tensile Strength

- Higher than normal concrete.
- ≈ **10–15% of compressive strength**.
- Improved due to dense paste & strong bond with aggregates.

Still brittle → cracks suddenly after peak.

3. Flexural Strength

- Significantly improved.
- Important for pavements, bridge decks.
- ≈ **15–20% of compressive strength**.

HPC with fibers → much higher flexural strength and toughness.

4. Modulus of Elasticity

- Higher stiffness than normal concrete.
- Typical HPC: **40–60 GPa**.

Depends on:

- aggregate stiffness
- compressive strength
- density

Higher E → smaller deflections in structures.

5. Stress–Strain Behavior

Characteristics of HPC curve:

- Linear up to high stress level
- Steep ascending branch
- Small strain at peak stress
- Sudden post-peak drop

👉 Indicates **brittle failure**.

Peak strain:

- Normal concrete ≈ 0.002
- HPC ≈ 0.002–0.003 (similar or slightly lower)

Ultimate strain smaller → less ductility.

6. Poisson's Ratio

- Similar to normal concrete.
- Typical: **0.18–0.22**.

Slight increase with strength.

7. Bond Strength with Steel

- Higher than normal concrete.
- Due to:
    - dense ITZ
    - low porosity
    - strong paste–aggregate interface

Benefits:

- better load transfer
- improved crack control
- shorter development length

8. Fracture Properties

HPC is:

- Higher fracture strength
- Lower fracture energy
- More brittle cracking

Crack propagation:

- passes through aggregates (not around them)
- due to strong ITZ

Fibers in HPC → improved toughness and ductility.

9. Shear Strength

- Higher than normal concrete.
- Due to:
    - higher compressive strength
    - aggregate interlock
    - dense microstructure

Used in:

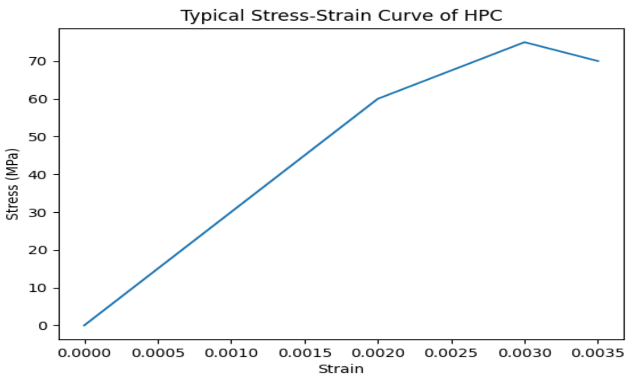
- prestressed beams

- high-load columns
- bridge girders

Comparison: HPC vs Normal Concrete

Property	Normal Concrete	HPC
Compressive strength	20–50 MPa	60–120+ MPa
Modulus E	20–40 GPa	40–60 GPa
Tensile strength	8–12% fck	10–15% fck
Flexural strength	Moderate	High
Bond strength	Normal	High
Ductility	Higher	Lower
Brittleness	Lower	Higher

Figure 1: Typical Stress-Strain Curve of High Performance Concrete



IV. DURABILITY PERFORMANCE

HPC exhibits enhanced resistance to chloride ingress, sulphate attack, and carbonation. Dense microstructure reduces permeability and improves long-term performance.

V. ENVIRONMENTAL IMPACT AND LIFE-CYCLE ASSESSMENT

Life-cycle assessment studies indicate that replacement of cement with SCMs reduces embodied energy and carbon footprint. Sustainable HPC contributes to long-term resource conservation.

Shape of HPC Stress–Strain Curve
Key characteristics:

1. Steep initial slope
2. Nearly linear elastic region up to high stress
3. High peak stress
4. Small peak strain
5. Sudden post-peak drop (brittle failure)

Stages of the HPC Curve

1. Linear Elastic Region

- Almost straight line.
- Extends up to ≈ **40–60% of ultimate stress**.
- Higher slope → higher modulus of elasticity.
- Very small microcracking.

2. Nonlinear Ascending Region

- Begins near **60–80% of peak stress**.
- Microcracks start forming.
- Still steeper than normal concrete.
- HPC remains stiff.

3. Peak Stress Point

- Maximum compressive stress (f'c).
- Peak strain ≈ **0.002–0.003**.
- Slightly lower or similar to normal concrete.
- Very limited plastic deformation.

4. Descending Branch (Post-Peak)

- Sharp stress drop.
- Sudden fracture.
- Low energy absorption.
- Brittle behavior.

Normal concrete → gradual drop
HPC → abrupt drop

VI. CHALLENGES AND FUTURE SCOPE

Challenges include higher material cost, quality control requirements, and limited field expertise. Future research should focus on nano-material integration and performance-based specifications.

VII. CONCLUSION

Sustainable High Performance Concrete offers improved mechanical and durability properties while reducing environmental impact. Continued research is essential to optimize cost and performance balance.

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