SCCT – Annual Concrete Seminar 2010

Application of High Performance Concrete in High-rise Buildings and Infrastructure

Presented by: Ir. Stephen Leung
Arup Materials Technology

Content

INTRODUCTION

Introduction
Definition of HPC

- High Performance Concrete (HPC) has been developed over the last two decades and introduced into construction industry
- HPC is one in which certain characteristics are developed for a particular application and environment.
- Key application for DURABILITY

Definition of HPC

- HPC is also often associated with High Strength Concrete (HSC)
- However, HPC is not necessary always a HSC.

High Strength Concrete (HSC)

Past	→	Compressive strength ~ 40MPa
Recent development in HK	→	Grade 60 – Grade 100
EN206 (supersede BS5328)	→	Compressive strength > C50/60

Choice of HPC

- The application of HPC will depend on desirable performance properties.
- Structural designer may draw out a list of design factor to govern the use of HPC.

Choice of HPC

- Structural Engineers should think of:
  - Strength requirement?
  - Stiffness requirement?
  - Congested rebar?
  - Protection to severe exposure environment?
  - Long term life cycle maintenance requirement?
  - Cost consideration?

PROPERTIES & CHARACTERISTICS OF HPC

Properties of HPC

- HPC can be designed to provide:
  - High strength / early strength
  - High Modulus of Elasticity
  - High Abrasion Resistance
  - Resistance to Chemical Attacks
  - High Durability and Long life in Severe Environments
  - Low Permeability and Diffusion
  - High workability
  - Compaction without Segregation

Properties of HPC

Table 1: Selected Properties of High Performance Concrete[9]

Property	Test method	Criteria that may be specified
High strength	ASTM C 39 (AASHTO T 22)	70 to 140 MPa (10,000 to 20,000 psi) at 28 to 91 days
High-early compressive strength	ASTM C 39 (AASHTO T 22)	20 to 28 MPa (3000 to 4000 psi) at 3 to 12 hours or 1 to 3 days
High-early flexural strength	ASTM C 78 (AASHTO T 97)	2 to 4 MPa (300 to 600 psi) at 3 to 12 hours or 1 to 3 days
Abrasion resistance	ASTM C 944	0 to 1 mm depth of wear
Low permeability	ASTM C 1202 (AASHTO T 277)	500 to 2000 coulombs
Chloride penetration	AASHTO T 259 & T 260	Less than 0.67% Cl at 6 months
High resistivity	ASTM G 59	
Low absorption	ASTM C 642	2% to 5%
Low diffusion coefficient	Under development by ASTM	
Resistance to chemical attack	Expose concrete to saturated solution in weldy environment	No deterioration after 1 year
Sulfate attack	ASTM C 1012	0.10% max. expansion at 6 months for moderate sulfate exposures or 0.5% max. expansion at 6 months for severe sulfate exposure
High modulus of elasticity	ASTM C 469	More than 50 GPa (7.5 million psi)
High resistance to freezing and thawing damage	ASTM C 666, Procedure A	Durability factor of 95 to 100 at 300 to 1000 cycles (max. mass loss or expansion can also be specified)
High resistance to deicer scaling	ASTM C 672	Scale rating of 0 to 1 or mass loss of 0 to 0.5 kg/m² after 50 to 300 cycles
Low shrinkage	ASTM C 157	Less than 400 millionths
Low creep	ASTM C 512	

Characteristics of HPC

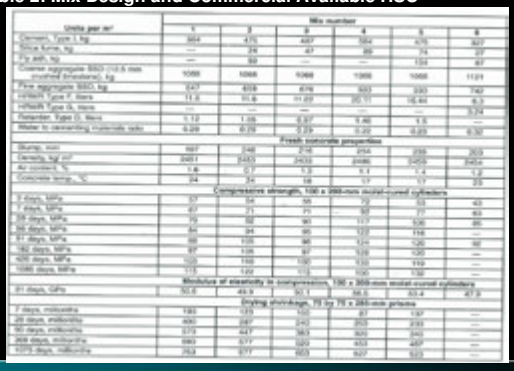
- In HPC, raw materials and admixtures are carefully selected and optimized to provide specific performance characteristics beyond conventional concrete.
- Quality Control plays a key role

Characteristic of HPC

- Performance characteristics for HPC are often achieved by
  - Reduced w/c's
  - use of micro silica
  - addition of PFA or GGBS
  - higher dosage of superplasticizer
- Additional attention will often need to be paid to other factors (e.g. heat of hydration)
- Again Quality Control plays a key role

Characteristics of HPC

Table 2: Mix Design and Commercial Available HSC [9]



Characteristic of HPC Factors Affecting Heat of Hydration

- Heat generated during cement hydration raises temperature of concrete
  - Mainly associated with large section size members such as pile cap and column
- Amount of cement
- High concrete placing temperature

Problems with High Concreting Temperature

- Tendency for cracks (plastic or thermal)
- High strength at initial stage but lower concrete strength in long-term

Rule of Thumb

- To estimate concrete peak temperature:
- Concrete placing temperature
- Temperature rise per kg of cement from heat of hydration
  - 5˚Cto 9˚C per 45kg of cement

Measures to Reduce Temperature Rise

- Low cement content, replace with other material (PFA, GGBS)
- Ice and cold water
- Cooling raw materials (e.g. aggregate / cement)
- Cooling pipe
- Reduce transport time

Characteristic of HPC - Thermal

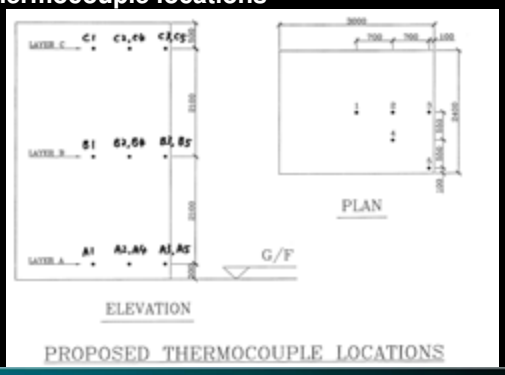
- Thermal control and study of HPC

Characteristic of HPC - Thermal

- On Site Control of Insulation

Characteristic of HPC - Thermal

- Thermocouple locations

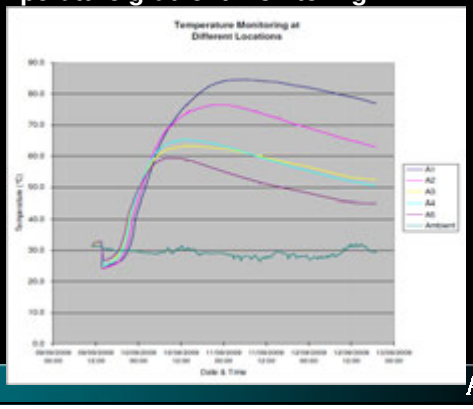


Characteristic of HPC - Thermal

- Example of thermocouple

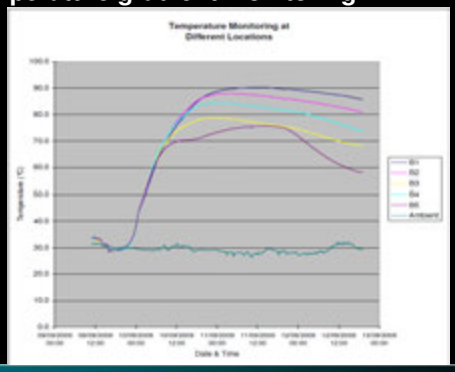
Characteristic of HPC - Thermal

- Temperature gradient monitoring



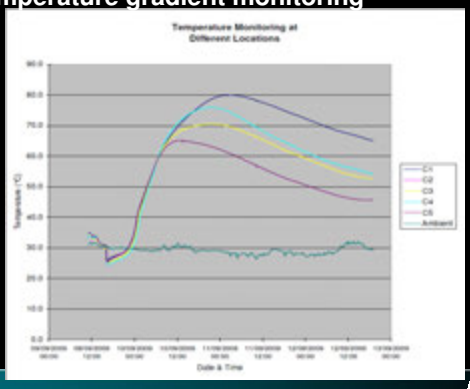
Characteristic of HPC - Thermal

- Temperature gradient monitoring



Characteristic of HPC - Thermal

- Temperature gradient monitoring



APPLICATION OF HPC

Applications of HPC

Example: High strength / early strength

Central Plaza, Grade 60, 1993

Applications of HPC

Example: High strength / early strength

One Island East, Grade 100, 2008

Applications of HPC

Example: Higher modulus of Elasticity

ICC Kowloon Station

Applications of HPC

Example: High Abrasion / Chemical Resistance

Waste Transfer Station

Applications of HPC

Example: High Durability and Long Life

Shenzhen Western Corridor

Applications of HPC

Example: Low Permeability and Diffusion

Tunnel Segmental Lining

Applications of HPC

Example: High Workability and Good compaction

Grade 80; Flow 700mm

QUALITY CONTROL OF HPC

Design and Control of HPC

- Prior to actual application of HPC, it is suggested a feasibility study is in place during design stage.
  - E.g. Study of heat of hydration / temperature effect
  - E.g. Study of chloride diffusion coefficient test
  - E.g. Produce a specific performance specification
- Designers should allow lead time in the works programme for pre-pilot studies and pre-trial mixes to achieve the desire performance characteristics.

Quality Control of HPC

- Attention to Ready Mix suppliers to demonstrate HPC quality control requirement
- Requirements may include:
  1. Design Stage – Control of Raw Material and Mix Design
  2. Control in Batching Production
  3. Control in Delivery Process
  4. Control of properties of fresh concrete on site
  5. Monitoring of properties of harden concrete on site

Stage 1 – Raw Material and Mix Design

- **Various guidelines :**
  - Code of Practice for Structural Use of Concrete 2004
  - BS 8110 Structural Use of Concrete
  - EN 206 Concrete – Specification, performance, production and conformity
  - BS 5328 Concrete – Guide to specifying concrete
- **Testing Scheme**

Stage 1 – Raw Material and Mix Design

- **Lab Trials**

Stage 1 – Raw Material and Mix Design

- **Plant Trials**

Stage 1 – Raw Material and Mix Design

- **Pump Trials**

Stage 1 – Raw Material and Mix Design

- **Column Trials**

On site trials – Trial Column with cooling pipes

Stage 2 – Batching Production

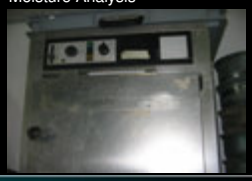
- Fulfill ISO 9001 Quality Management System
- Quality Scheme for the Production and Supply of Concrete (QSPSC)
- Focus on production control process
  - weighing tolerance
  - delivery records
  - calibration of equipment
  - product test results

Production Control Panel in batching

Aggregate Sieve Analysis

Aggregate Stockpile

Moisture Analysis

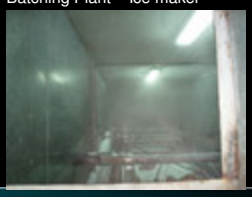


Chill water facility

Stock Pile of ice

Batching Plant – Ice water

Batching Plant – Ice maker



Stage 3 – Delivery

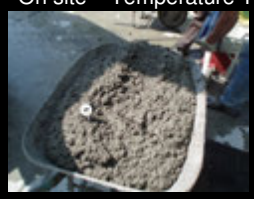
- Delivery records
- Trip tickets shows time of batching and any special remarks of the concrete that is going to be delivered on site.

Stage 4 – Control of fresh concrete

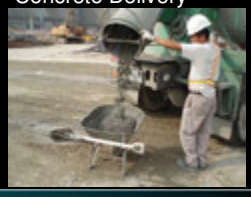
- More stringent requirement than ordinary concrete
  - Consistence, flow, slump
  - Placing temperature
- Testing – CS1 will not usually be sufficient
- Sampling frequency of HPC is also often increased

On site – Slump Test

On site – Temperature Test



Concrete Delivery



On site – Slump Flow Test

On site – Preparation of cube samples

On site – Cylinder Test

On site – More Stringent Temperature Control

Stage 5 – Monitoring of Hardened Concrete

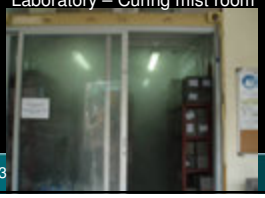
- **May increase testing frequency of cube samples (e.g. cube strength at 3d, 7d, 28d, 56d)**
- **Careful selection of In-situ core test (try to minimize destructive test)**
- **Monitoring strength performance**

Testing of Hardened Concrete

Laboratory – Curing tanks

Laboratory – Compressive test

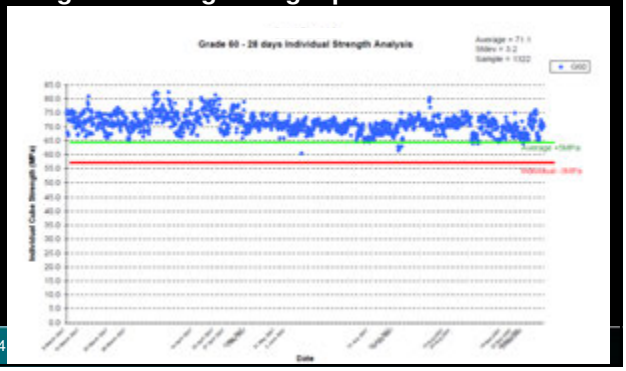
Laboratory – Curing mist room



Laboratory – Fracture failure after compression

Stage 5 – Control of Hardened Concrete

- **E.g. Monitoring strength performance**



Conclusion

- **In order for successful application of High Performance Concrete in High rise Buildings and Infrastructure, special attention is required:**
  1. Structural Design Requirement
  2. Feasibility Study Allow time for pre pilot study
  3. Develop practical and specific performance specification
  4. Stringent Quality Control through different stages of concrete supply
  5. Monitoring Works

Reference

- [1] http://www.expresswaysonline.com/expwys/news_hpc.htm
- [2] http://knowledge.fhwa.dot.gov/cops/hpcx.nsf/home
- [3] http://www.geocities.com/samshank/hpc.pdf
- [4] http://www.orsm.net
- [5] BS 5328 *Concrete Guide to specifying concrete*
- [6] BS 8110 *Structural Use of Concrete*
- [7] Code of Practice for Structural Use of Concrete 2004
- [8] EN 206 *Concrete Specification, performance, production and conformity*
- [9] Kosmatka, Kerkhoff, Panarese, *Design and Control of Concrete Mixtures*, Portland Cement Association, 2002
- [10] Neville A.M., *Properties of Concrete Fourth Edition*, Addison Wesley Longman Limited, 1995

Q & A

Thank You