High Performance Concrete

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Most ready-mixed concrete producers are familiar with the concept of "performance concrete." Performance concrete implies that specifications will stipulate minimum concrete strengths and leave the proportioning of the concrete mixture to the concrete producer. However, lately, another similar term, "high-performance concrete," is being heard in the industry. This article examines what high-performance concrete (HPC) is, what its properties are, what materials are needed to produce it, what role the engineer must play in regards to HPC, and where it is being specified and used.

What is High-Performance Concrete?

In 1990, researchers at the Strategic Highway Research Program (SHRP) defined a HPC as concrete meeting one of the following requirements:

- 4-hour compressive strength > 3,000 psi
- 24-hour compressive strength > 5,000 psi
- 28-day compressive strength > 10,000 psi
- Water-cementitious materials ratio < 0.35

Also, the concrete must have a durability factor greater than 80 after 300 cycles of freezing and thawing to meet their definition,

The American Concrete Institute (ACI) formed a special committee on HPC in 1992. This committee has taken a broader view of HPC to include performance aspects other than compressive strength in its definition (this definition is similar to an earlier definition proposed by the National Institute of Standards and Technology):

Concrete meeting special performance and uniformity requirements which cannot always be achieved routinely using only conventional constituents and normal mixing, placing and curing practices. These requirements may involve enhancements of the following:

- *Ease of placement and completion without segregation*
- *Long-term mechanical properties*
- *Early-age strength*
- *Toughness*
- *Volume stability*
- *Long life in severe environments*

In a nutshell, HPC is simply concrete which is expected to provide superior performance in a particular application. That application may or may not require a higher compressive strength. Note that unlike the performance concretes which are seen in today's specifications, the sole responsi-

Table 1— Some Typical Properties of High Performance Concrete

High Ultimate Strength

- 6,000 to 10,000 psi compressive strength at 28 or 56 days
- 10,000 to 18,000 psi compressive strength at 56 days

High Early Strength (18 to 24 hours)

- 2,500 to 4,000 psi compressive strength
- 400 to 600 psi flexural strength

High Modulus of Elasticity

- Greater than 6,500,000 psi

High Durability

- Protection against corrosion of embedded steel
- Protection against other severe service environments

High Workability, Pumpability and Finishability

- Mid-range concrete: 6 to 8 in. slump
- Flowing concrete: greater than 8-in slump, without segregation
- Reduced pumping pressures
- Easier finishing
- Self —consolidating

Placable in Cold Weather

- Normal setting time
- Accelerated strength gain
- Low temperatures freeze protection

Placable in Hot Weather

- Normal slump retention
- Control of hydration

Controlled Hydration

- Extended setting time as required by project conditions

Table 2—Admixtures for High-Performance Concrete

Admixture Category	Applications/Uses	Standards	Considerations for Most Effective Use
Conventional Admixtures	• Water Reducers • Retarders • Accelerators • Combinations	ASTM 494 Types A, B, C, D, E	• Allow use as requested by producer or contractor
Superplasticizers	• Greater Water reduction 12 to 30+% • Flowing Concrete • Increased Pumpability • Self-consolidation	ASTM C 494	• Allow slumps in excess of 8 in. • Allow free fall of 15 to 25 ft. • Allow redosing, if necessary • Allow batch plant addition
Silica Fume	• High Strength • High Durability	AASHTO M-307 ASTM in progress	• Must include use of superplasticizer specify amount • Specify amount suitable to the application
Corrosion Inhibitors	• Extend time to corrosion caused by deicing salts or marine exposure	None	• Allow use as required by conditions
Non-Chloride accelerators	• Improved setting at low temperatures • Improved strength gain characteristics	ASTM C 494 Types C and E	• Reduce protection time • Allow early form removals
Cold Weather admixtures	• Allows concrete to set at ambient temperatures as low as 20°F • Reduced winter protection	None	• Reduce winter heating/ concrete • Allow placements without protection
Hydration control admixtures	• Extend setting time • long haul applications	None	• Allow use of treated concrete • Allow increased haul time

Reprinted from **CONCRETE PRODUCTS**, June 1993

bility for proportioning a HPC to meet the enhanced performance level is not necessarily on the concrete producer.

What Are the Properties of High-Performance Concrete?

The definitions above list some of the general performance enhancements that fall into the category of HPC. More specific examples of the performance characteristics of HPC, which are being specified today, include high-ultimate strength; high-early strength; high modulus of elasticity; high durability; increased workability, pumpability, and finishability; increased placeablilty in hot and cold weather; and absolute control of concrete hydration. These performance properties are described in more detail in Table 1.

More than one of the properties of HPC mentioned may be required for a given project. For example, a high-rise structure may require a concrete with high-ultimate strength, high modulus of elasticity, high pumpability and the ability to be placed without consolidation. More than one HPC may be required on a particular project. The same high-rise structure may also require a concrete which has a high resistance to corrosion damage for an attached parking structure.

What Materials are Typically Used to Produce HPC?

The basic materials used to produce day-to-day concrete-cement, aggregates, water and admixtures–are also used to produce HPC. The most noticable differences will be increased cement contents, reduced water contents and increased use of chemical and mineral admixtures. In the area of cementitious materials, it is not unusual to see combinations of three materials: portland cement, fly ash and silica fume or portland cement, ground granulated blast-furnace slag cement and silica specifying of HPC beyond stating what they expect the hardened concrete to do in place. An engineer must not ask for performance on one hand and take away options on the other hand. For example, restrictions on slump or the requirement to verify a certain slump before a superplasticizer is added will limit the performance that can be expected of a given concrete.

ACI is currently going through all of its documents and standards with the intention of removing any barriers to the use of HPC from those documents. These barriers include upper limits on slump, time-based rather than strength-based criteria for form removal and building code requirements that hinder the use of HPC. Other considerations that need to be addressed regarding using admixtures in HPC are included in Table 2.

Where Does The Industry Stand Today?

Many concrete producers are already working with HPC; they simply haven't associated what they are currently doing with this name. Whether the material is called HPC or something else, the concept of expecting and specifying more than simply compressive strength from concrete is here to stay. Chemical and mineral admixtures will play a major role in the production of HPC. Concrete producers who follow and understand this trend will be the leaders in their markets □

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