High-performance concrete: As high as it gets!

Producer uses three cementitious materials to achieve high early strength for form stripping and keep the concrete cool after a 50-minute haul

Workability was a major concern because the contractor had to place high-early strength concrete in heavily reinforced walls and slabs by pumping, chutes or buckets.

High-performance concrete is a widely used term in the concrete industry today without any generally accepted definition (See related article, page 503). A project that called for nuclear waste-containment concrete pushes the HPC concept to the limit.

This project is the recently completed Canister Storage Building at the Hanford Nuclear Site near Richland, Wash. The building has three bays that each will store 226 canisters of spent nuclear fuel. The facility, part of an overall cleanup of the Hanford Site, will store 2,100 metric tons of this material.

The specification requirements for the concrete are impressive:

- 75-year design life
- Terrorist-proof
- 5000-psi compressive strength at 28 days
- 6000-psi compressive strength at 90 days
- 5- to 9-inch slump at placement
- 2% to 6% air
- Maximum 70°F concrete temperature at delivery
- Maximum temperature gain of 30°F at 48 hours
- 15,000 cubic yards
- 50-minute haul time

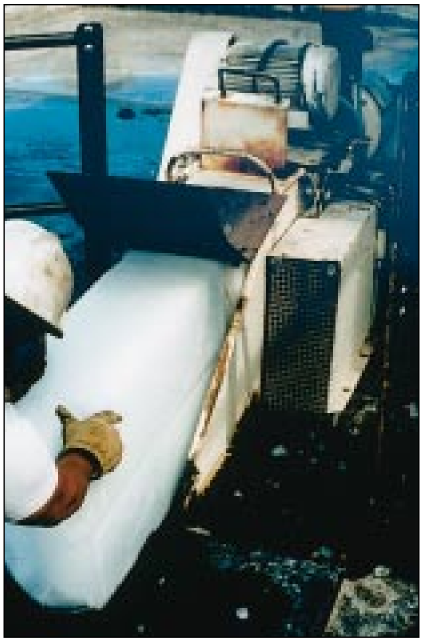
The first reaction of Scott Bennett, quality control technologist for concrete producer Cornerstone/Acme Materials & Construction, Richland, Wash.: "I wished we had a batch plant on site because the haul-time and temperature restrictions were going to make it hard to stay in spec." When pricing the concrete, Acme factored in a substantial element of risk to account for any rejected concrete. However, after completing Phase I of the project, they found that maintaining uniformity of the fresh-concrete properties wasn't as big a problem as suspected. They then reduced their concrete price for the rest of the job, thus benefiting the owner.

Strong, but too hot

The concrete mixture Bennett first put together contained 500 pounds of Type II cement and 125 pounds of Class F fly ash per cubic yard with a maximum water-cementitious materials ratio of 0.45. The 2- to 4-inch initial slump went to 7 to 9 inches after addition of a high-range water reducer.

While this concrete mixture met the requirements of the specification, it caused problems for the contractor. This situation isn't unique. On projects with complex requirements for hardened-concrete performance, the specifier's requirements and the contractor's needs are often incompatible. In this case, meeting the tight concrete temperature-gain limit was at odds with the contractor's need for early strength to allow stripping of wall forms in a reasonable time. The project specs called for 4000 psi before the walls could be stripped, and the first mixture produced excessive heat gain during the first 48 hours.

With the help of Dave Kriska, senior sales rep, Master Builders, and Arden Sanford, field engineer for project designer Fluor Daniel Northwest, Richland, Wash., Bennett reproportioned the concrete. The new mixture



To keep the concrete temperature below 70°F, the producer had to add up to 1,000 pounds of chipped ice to the 10-yard trucks. To control water content, workers weighed the ice blocks before chipping them.

contained 390 pounds of Type II cement, 150 pounds of Class F fly ash and 60 pounds of silica fume per cubic yard, with a 0.35 water-cementitious materials ratio. The mixture also contained 150 fluid ounces of high-range water reducer and 84 fluid ounces of mid-range water reducer per yard, plus the air-entraining admixture dosage needed to achieve the specified air content.

Note the lower cement content and the higher fly-ash content than those of the original mixture, and the addition of silica fume. A pound of silica fume produces about the same amount of heat as a pound of portland cement and yields about three to five times as much compressive strength.

Thus the strength contribution of the silica fume in this concrete was about the equivalent of 180 to 300 pounds of cement per cubic yard. Because silica fume's contribution to early-age strength is significant, the revised mixture was able to meet the temperature requirements and produce the needed early strength.

There were no special requirements for the aggregates, and a 1-inch-maximum-size coarse aggregate meeting the grading requirements of ASTM C 33 (No. 57) was used.

Concrete cooling needed

The contractor placed most of the concrete in the summer, when ambient temperatures often exceeded 90°F. To stay below the 70°F concrete-temperature limit, the batchman added 900 to 1,000 pounds of ice to each 10-yard load. When aggregate moistures were taken into account, the use of this much ice left only 10 to 20 gallons of water to add to each load. Ice blocks were stored in refrigerated trucks at the plant. Cornerstone/Acme weighed the ice, recorded weights on the batch tickets and added the ice to the trucks using a commercial chipper.

Constructability concerns

Workers placed the concrete in walls and a deck slab by chute, bucket and pump. The heavily reinforced walls are up to 34 feet high and 4½ feet thick, and the 5-foot-thick deck slab contains 4,500 yards of concrete and 29 mats of reinforcing steel made up of #9, #11 and #14 bars. Because of rebar congestion, the contractor worried about workability and quality of the off-the-form wall finish. Finishability of the deck slab concrete was also a concern.

However, "workability was excellent, despite the very low water-cementitious materials ratio," Bennett notes, "and after the carpenters stripped the forms, both the contractor and owner were satisfied with the finish. No additional sacking or other repairs were required."

Cornerstone/Acme raised the w/cm to 0.37 to improve finishability of the slab concrete. Workers made three 1,500-yard deck placements, each tak-

ACI's latest definition of high-performance concrete

High-performance concrete is defined as concrete meeting special performance and uniformity requirements that cannot always be routinely achieved using only conventional constituents and normal mixing, placing and curing practices. These requirements may involve enhancements of one or more of the following:

- Ease of placement and compaction without segregation
- Long-term mechanical properties
- Reduction in permeability
- Early-age strength
- Decrease in heat of hydration
- Toughness
- Volume stability
- Long life in severe environments

Commentary

High-performance concrete is a concrete in which the properties and characteristics are optimized for a particular application and environment. The properties that differentiate HPC from other concrete can include hardened-concrete properties such as compressive strength, modulus of elasticity, unit weight, shrinkage, creep, freeze-thaw resistance, scaling resistance and abrasion resistance, or fresh-concrete properties such as consistency, workability and finishability.

These properties may be used individually or in combination to describe an HPC, provided performance requirements go beyond those routinely achieved with conventional constituents and normal mixing, placing and curing practices. Many properties of HPC are interrelated, and a change in one property can result in changes in other properties. Consequently, the designer may need to optimize several properties for the intended application and then clearly specify the required properties in the contract documents.

ing about 12 to 14 hours. Technicians checked slump and air content at 50-yard intervals and made test cylinders for every 150 yards.

Day-to-day performance was consistently good. Walls were typically ready for stripping at eight days. Compressive strengths averaged 6300 psi at 28 days and 7500 psi at 90 days. One core taken from a wall reached nearly 11,000 psi at 56 days and had a rapid-chloride permeability test result of less than 200 coulombs.

Truck coordination important

Both Bennett and Steve Wittstock, quality control manager for Cornerstone/Acme, agreed upon their biggest problem during the project: truck coordination. As Bennett says, "With a 50-minute haul time and high production rates, good communication between the contractor and Acme was essential to ensuring proper delivery." Wittstock added that any placement delays were especially troublesome, since there was always a lot of concrete on the road. Because of this, the 90-minute maximum delivery time limit in ASTM C 94 was waived and QC personnel redosed the concrete with super or AEA or both if there was a delay.

This project truly represents and defines the concept of HPC. The concrete met the requirements of:

- The producer, who was able to produce and deliver it consistently
- The contractor, who had a tight construction schedule
- The owner, who had stringent durability requirements. ■

—TERRY HOLLAND

Hanford Nuclear Site Canister Storage Building project

- **Concrete producer:** Cornerstone/Acme Materials & Construction, Richland, Wash.
- **Owner:** U.S. Department of Energy
- **Designer:** Fluor Daniel Inc., Irvine, Calif.
- **Contractor:** David A. Mowat, Woodining, Wash.
- **Admixture supplier:** Master Builders, Cleveland
- **Cement supplier:** Ash Grove Cement Co., Durkee, Ore.
- **Fly ash supplier:** Pozzolanic Northwest, Centralia, Wash.

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