High-Performance Concrete: North Carolina Field Installation Results

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A Strategic Highway Research Program contract included five installations in five states. The objectives of the field installations were to confirm the ability to produce and place certain high-performance concretes and to achieve desired strength-time targets under realistic conditions, with several sources of raw materials. Data obtained from the most extensive field trials, conducted in North Carolina, are presented and examined.

High-performance concrete (HPC) may be defined as concrete with enhanced durability and strength-time performance. Field testing of an HPC was conducted as part of a Strategic Highway Research Program (SHRP) contract in Arkansas, Illinois, Nebraska, New York, and North Carolina. The most extensive field trials occurred in North Carolina; this report examines those results.

OBJECTIVE AND SCOPE

The primary objective of the North Carolina field installation was to

1. Verify the ability to reproduce HPC under realistic field conditions,
2. Verify lab results for strength-time data, and
3. Identify potential problems not encountered in the lab.

Both insulated and noninsulated sections were investigated. Two types of coarse aggregate and two types of high-range water reducer (HRWR) were used. In addition, sections were constructed at both a deliberate rate and under more typical construction rates.

SITE DESCRIPTION

A two-lane experimental approach slab, approximately 55 m (180 ft) long, to a bridge was placed using HPC. The bridge was under construction on US-17, over the Roanoke River in northeastern North Carolina just north of Williamston. Weather during this period was very hot and humid. Daytime temperatures ranged from the low 20s to the mid-30s in degrees Celsius (mid-70s to mid-90s Fahrenheit).

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The concrete pavements was unreinforced, jointed at intervals of 4.6 m (15 ft) and doweled at the end of each day's placement with a maximum of 36.6 m (120 ft) between doweled sections. The concrete was placed on an asphalt base course. Depth of the pavement was a minimum of 23 m (9 in.).

Three 18.3-m (60-ft) sections were placed in the passing lane at a rate that allowed more extensive testing. The fourth section was the driving lane. Using typical placement rates, all 54.9 m (180 ft) were placed in 1 day (see Figure 1).

MATERIALS

Nominal batch weights of HPC used in this project are as follows:

- Cement: 516 kg/m^3 (870 lb/yd^3)
- Added water: 160 kg/m^3 (270 lb/yd^3)
- DCI: 20 L/m^3 (4 gal/yd^3)
- Total water: 178 kg/m^3 (300 lb/yd^3) [total water includes that contributed by DCI, air entraining agent (AEA), and HRWR]
- AEA: dosage as necessary, but as high as 0.9 L/m^3 (2.5 oz/cwt) was required.
- HRWR: up to 8.1 L/m^3 (24 oz/cwt) of naphthalene HRWR or 8.8 L/m^3 (28 oz/cwt) melamine HRWR; much higher dosages tended to produce unacceptable strengths at 6 hr due to excessive retardation.
- Coarse aggregate quantities (saturated surface dry): about 1020 kg/m^3 (1,720 lb/yd^3) for the crushed granite and 970 kg/m^3 (1,640 lb/yd^3) for the marine marl; sand quantities were adjusted as necessary to provide a yield of 1 m^3 (27.0 ft^3/yd^3) at minimum air content.

Type III portland cement was used, with a 5500-blaine fineness and slightly more than 0.6 percent alkalies as sodium oxide.

A 30 percent solution of calcium nitrite, $Ca(NO_2)_2$, tradenamed Darex Corrosion Inhibitor™ (DCI), produced by W.R. Grace, was used in all the HPC. DCI is typically used to reduce the corrosion rate of reinforcing steel, but it is also a powerful set accelerator. It was therefore selected as a nonchloride accelerate that would also improve long-term durability of reinforced structures such as bridge decks.

DCI could not be added at the time of batching because of rapid slump loss. Mixtures containing a retarder were not used

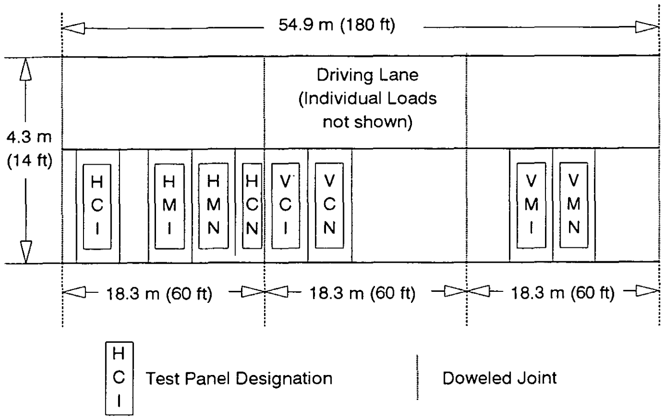

FIGURE 1 SHRP C-205 field installation layout, North Carolina.

because they retarded early strength development. DCI contains a substantial amount of water that must be withheld during batching.

The concrete contained either a naphthalene-based HRWR produced by W.R. Grace or a melamine-based HRWR produced by Cormix. The only other admixture used was Micro-Air, an AEA manufactured by Master Builders, Inc.

Either crushed granite or marine marl coarse aggregate meeting ASTM C33 #57 specifications was used. Virtually all the aggregate passed the 25-mm (1 in.) sieve. The crushed granite was a hard, angular aggregate of low absorption (0.4 percent). The specific gravity, saturated surface dry (SSD) was 2.64. The marine marl was a cubical to subangular, relatively porous, high-absorption (typically over 4.5 percent, but variable) shell limestone. The specific gravity, SSD of the marl was typically 2.48. Fine aggregate was the same in all mixes.

Test panels were designated by three letters. The first letter indicated the type of HRWR: H for naphthalene-based or V for melamine-based HRWR. The second letter indicated the type of aggregate: C for crushed granite or M for marine marl. The third letter designated whether the slab was insulated: I for insulated or N for noninsulated.

PRODUCTION, PLACEMENT, CURING, AND SAWING

The ready-mixed-concrete supplier operated a small dry-batch plant in Williamston. The plant did not have automated moisture control. The lack of automated moisture control and the sensitivity of the mix to variations in water created difficulty in maintaining the desired level of quality control. Because of scale capacity, batches were weighed out in two equal halves. Because of this, and adding the HRWR by hand, batching time was generally just under 10 min.

Field trial batches of 1.5 to 2.5 m^3 (2 or 3 yd^3) were conducted to fine-tune the mix for the raw materials used and to permit crews and supervisors to practice handling techniques. Strength levels were confirmed.

The trial batches went reasonably well, but early loads indicated difficulty in mixing, and subsequent batch sizes were reduced. Batch sizes were typically half the rated mixing capacity of the truck.

The specific batch sequence used for the North Carolina installation was to first load one-third of the batch water and two-thirds of the HRWR into the truck. Then, with the drum rotating at mix speed, approximately a third of both the fine and the coarse aggregate were added. Then the cement was ribboned in with the remaining aggregate. All of the AEA, the remaining water, and HRWR were then added. Typically 10 to 20 L (3 to 5 gal) of batch water, depending on the batch size, was held back for washing down the hopper during plant mixing. After mixing for a minimum of 70 revolutions at the plant, the mix was checked, at least visually, and sent to the job site.

The batch plant was close to the job site, and travel time was between 5 and 10 min. The DCI was added by hand and mixed, and the load was discharged. The concrete was placed by a bridge deck machine on rails, followed by hand floating and a burlap drag. The surface was tined as soon as possible and immediately covered with curing compound.

On sections to be insulated, plastic sheets were spread on the surface once it was tack-free. A sheet of rigid-foam building insulation 25 mm (1 in.) thick was then placed on the slab with weights to hold it down. Insulation was removed at the end of 6 hr.

Significantly, no cracking due to plastic shrinkage was noted on any of the slabs. Although the high humidity certainly contributed to this, other factors were important. First, everyone was anxious to get the surface finished and curing compound applied as soon as possible. The contractor would frequently mist the area, which was beneficial since these were nonbleeding mixes. Furthermore, the mixes were probably gaining strength faster than they were losing moisture; shrinkage-induced stresses were less than the strength of the concrete.

Premature cracking due to delayed sawing was a problem in two cases, though, for which sawing was delayed until the following day. In both cases, the slab had either cracked already or cracks ran out ahead of the saw blade. HPC may be more prone to cracks resulting from delayed sawing because of volume changes of the concrete at very early ages as it undergoes significant temperature changes. Interestingly, crack spacing was approximately 4½ m (15 ft).

Four test panels were placed during the first day, all containing naphthalene HRWR. Two panels were insulated, and two remained uncovered. One of the insulated panels was placed using crushed granite (HCI) and the other using marine marl (HMI), as were the noninsulated panels (HCN and HMN). Sections were completed with concrete of the same type as being tested.

Two test panels were placed in the next section. The concrete placed here contained crushed granite and melamine HRWR. One panel was insulated (VCI) and the other panel was not (VCN). Two test panels were also placed in the third section, which contained concrete produced using marine marl and melamine HRWR. Again, one panel was insulated (VMI) and the other panel was not (VMN).

The driving lane, placed in 1 day, contained both crushed granite and marine marl. Only routine testing was conducted on these mixes, since the primary purpose was to examine the effects of routine production rates on variability of the concrete as delivered.

TESTING PLAN

Slump and air content using the pressure method were determined for each batch. Cylinders 100 × 200 mm (4 × 8 in.) were fabricated for each panel for testing at 6 hr, 1 day, 7 days, 28 days, 6 months, and 1 year, using plastic molds with tightly fitting lids.

Where the concrete was to be insulated, the cylinders were also initially insulated by being placed in specially constructed "cubes" made by gluing layers of closed-cell, rigid-foam building insulation together and sawing out holes for the cylinders (in their molds). A fully loaded cube could be lifted by two individuals.

Beams 100 × 100 × 400 mm (4 × 4 × 16 in.) were cast in some cases; however, test results were extremely variable and beam data provided little useful information.

A number of Type-T copper-constantan thermocouples were placed in the pavement and in some cylinders to monitor temperatures.

Cylinders were transported to the North Carolina Department of Transportation testing laboratory, close by in Williamston, either just before testing at 6 hr for insulated cylinders or at about 20 hr for all other cylinders. All insulated cylinders were removed from the insulating cubes at 6 hr, regardless of age at testing. Cylinders were stored outside the laboratory until tested. The cylinders remained in the plastic molds, after the lids had been removed at 1 day. The cylinders were thus exposed to conditions that were very similar to those of the pavement.

Rapid chloride permeabilities (RCPs) were determined in accordance with AASHTO T277 from specimens cut from the top of cores removed from the slab. Duplicate cores were used to obtain specimens for determination of RCP, as opposed to two slices from the same core.

TEST RESULTS AND DISCUSSION OF RESULTS

A synopsis of data for all test panels is given in Tables 1 and 2. Nominal water-cement ratios for all mixes were between 0.33 and 0.35. All results are the average of two specimens. The 28-day core results are not shown because they were accidentally taken at the wrong locations.

Seventeen batches of concrete were produced during the 3 days of slow construction rate placement. Slumps ranged from 45 mm (1¾ in.) to 150 mm (6 in.); 70 mm (2¾ in.) was the average. Air contents during this period ranged from 4.2 to 9.2 percent, with an average of 6 percent.

Sixteen batches were produced in the long section placement. All concrete placed there was to be noninsulated, and somewhat higher dosages of HRWR were used to increase the slump. Slumps during this phase of construction ranged from 50 mm (2 in.) to 240 mm (9½) in., with a 130-mm (5-in.) average. Air contents ranged from 4.4 to 10.3 percent, with an average of 7 percent.

Air contents and slumps were generally within desired limits; but variability in slump and air during the long placement was higher than that during the shorter, slower placements. Although this variability may be related to some reduction in the level of batch to batch control, much of it, along with generally higher values of slump and air, may be due to holding trucks for a shorter time for testing and adjustment.

Two strength-time criteria—14 MPa (2,000 psi) at 6 hr and 34 MPa (5,000 psi) at 24 hr—were investigated. Strengths of insulated panels met the 6-hr target in all but one case. Strengths of noninsulated panels were also relatively high. This is almost certainly due to the high ambient temperatures at the time of placement. Two mixes, VMI and VMN, did not meet the required strength at 6 hr. These mixes contained a very large quantity of HRWR, which caused retardation of the mix and low early strengths, although strengths at 1 day were comparable to the other mixes.

Strengths at 1 day did not all meet the criteria for 24-hr strength but were fairly close. Average 1-day cylinder strength for the test panels was greater than 34 MPa (5,000 psi), however. Average 28-day cylinder strength was about 50 MPa (7,300 psi).

Crushed granite mixes had higher strengths than did mixes produced with marine marl. Additionally, mixes

TABLE 1 Concrete Batch Properties, SHRP C-205 Field Data Synopsis, Williamston, N.C.

ID	HCI	HMI	HMN	HCN	VCI	VCN	VMI	VMN
Batch (m^3)	4.6	4.6	3.1	3.1	3.1	4.6	4.6	4.6
Batch (yd^3)	6	6	4	4	4	6	6	6
Slump (mm)	90	55	55	150	75	90	75	45
Slump (in)	3 ½	2 ¼	2 ¼	6	3	3 ½	3	1 ¾
Air (%)	6.1	5.5	6.8	4.9	6.2	5.7	8	6.4
Cylinder Temp (°C)								
placed	33	32	33	32	32	31	32	35
max	na	61	60	57	na	na	na	na
Slab Temp								
placed	32	34	34	na	32	33	34	35
max	na	67	52	na	59	57	na	na

"na": data not acquired; °F = (1.8 × °C) + 32

TABLE 2 Compressive Strengths and RCP, SHRP C-205 Field Data Synopsis, Williamston, N.C.

ID	HCI	HMI	HMN	HCN	VCI	VCN	VMI	VMN
Cylinder Strength (MPa)*								
6 hrs	16.0	22.5	15.2	12.3	14.9	9.2	2.9	2.6
1 day	36.4	42.0	33.4	31.5	35.6	36.5	33.2	32.4
28 days	52.4	53.0	50.4	53.5	48.3	50.7	42.1	45.3
6 mo	61.8	63.3	57.0	63.6	58.2	63.6	50.1	52.5
12 mo	65.3	64.3	55.2	65.8	61.4	63.6	49.3	52.9
18 mo	70.4	62.2	59.2	70.7	65.5	67.2	51.0	54.9
Cylinder Strength (selected) (psi)*								
6 hrs	2320	3260	2200	1780	2160	1340	420	380
1 day	5280	6090	4850	4570	5170	5290	4820	4700
28 days	7600	7680	7310	7760	7000	7360	6100	6570
18 mo	10,210	9020	8580	10,250	9510	9750	7400	7960
Core Values at 12 months								
fc (MPa)	60.3	51.5	47.5	66.9	61.4	62.6	45.6	55.4
fc (psi)	8750	7470	6890	9700	8910	9080	6620	8030
RCP (c)*	1650	3160	1150	2000	1510	1030	2260	1810

* *Compressive strength from 100 mm x 200 mm (4"x8") cylinders, cores 100 mm (4") diameter; RCP: rapid chloride permeability (coulombs), all values are the average of two specimens.*

with naphthalene HRWR tended to outperform mixes with melamine HRWR at later ages, as expected. HPC continued to gain strength with time, under typical field exposure conditions.

RCP results indicate that the concrete is only moderately permeable to chlorides, although results are generally low. These results should be viewed with caution, however, because the presence of any soluble salt, such as calcium nitrite, can increase the measured value by reducing the resistivity of pore solution in the concrete. The concrete is therefore probably less permeable than RCP data indicate. There is no clear pattern to RCP values on the basis of the type of insulation, aggregate, or HRWR.

CONCLUSIONS AND RECOMMENDATIONS

A thorough briefing of all participants before any construction and adequate full-size trial batches to adjust mix proportions and give the participants practice in handling the concrete is essential.

Stricter-than-usual control of aggregate moisture is required because of the increased sensitivity of HPC to water content.

Mixing capability of trucks is critical, particularly in a dry-batch operation. Volume of HPC batched should exceed neither two-thirds of the rated mixing capacity of a ready-mixed-concrete truck nor, in many cases, half of the rated mixing capacity.

No apparent problem was found with plastic shrinkage cracking of these pavements; however, sawing of concrete must occur as early as practicable.

Using insulation, it is possible to attain compressive strengths of 14 MPa (2,000 psi) within 6 hr under typical summer working conditions in North Carolina, using HPC. One-day strengths of 34 MPa (5,000 psi) were attained in all cases with 6 hr of insulation, but without insulation, strengths were frequently 1.5 to 2 MPa (200 to 300 psi) below the 34-MPa (5,000-psi) criteria.

HPC continues to gain strength with time, under typical field exposure conditions and without exposure to continuous moist curing.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support provided by SHRP, a unit of the National Research Council authorized by Section 128 of the Surface Transportation and Uniform Relocation Assistance Act of 1987. The authors also appreciate the contributions of the general contractor, the ready-mixed-concrete supplier, and the raw materials suppliers, without whose whole-hearted cooperation these investigations would have been impossible. In particular, the cooperation and patience of the North Carolina Department of Transportation are deeply appreciated.

Publication of this paper is sponsored by Committee on Mechanical Properties of Concrete.