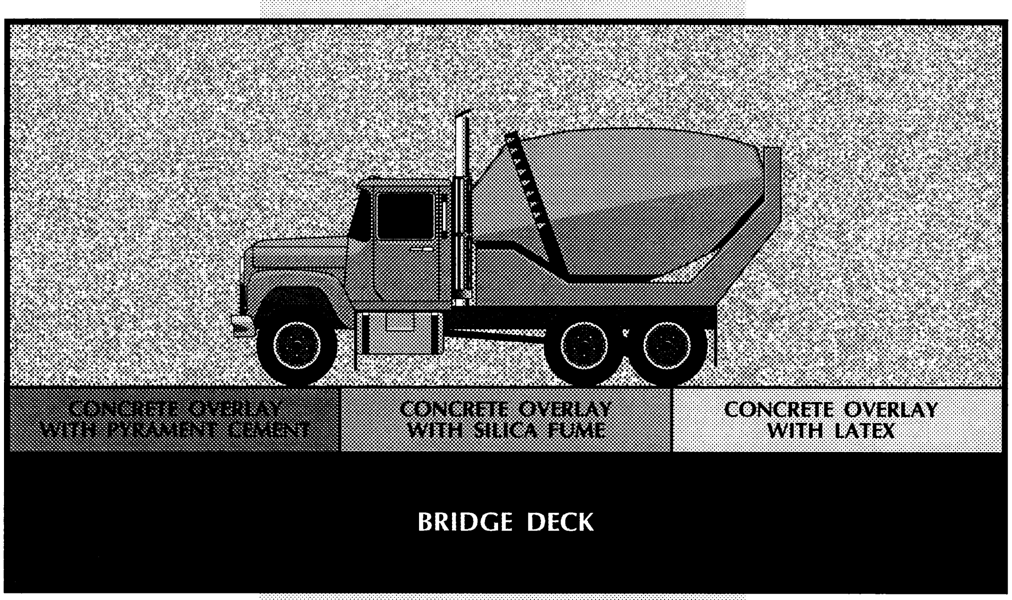
FINAL REPORT

A FIELD INVESTIGATION OF CONCRETE OVERLAYS CONTAINING LATEX, SILICA FUME, OR PYRAMENT CEMENT



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16. Abstract

This study evaluated latex-modified concretes (LMC) and concretes containing silica fume (SFC) or Pyrament-blended cement (PBCC) in bridge deck overlays in the field. The condition of the overlays was monitored for 4 years. LMC and SFC were placed in 2 days using a vibratory roller screed spanning half the width of the bridge, each side in 1 day. PBCC was placed in small segments, each covering half the width of the bridge, in 2 months. The placement in small segments was dictated by traffic control requirements. PBCC was used with no admixtures. Similarly, LMC was used with no admixture except the latex-modifier.

The results indicate that LMC, SFC, and PBCC have low permeability and satisfactory strengths. PBCC develops high very early strengths within hours, even in cold weather, and SFC develops sufficient compressive strength for opening to traffic in 1 day. Since all three concretes are prone to plastic shrinkage, proper and immediate curing are essential.

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

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INTRODUCTION

Chloride-induced corrosion of uncoated reinforcing steel in bridge decks is common and results in costly repairs.[1] In the rehabilitation of these decks, one widely used protective system is a thin, low-permeability, concrete overlay with a minimum thickness of 32 mm (1¼ in). Over the years, latex-modified concrete (LMC) has been successfully used in such overlays.[2] Recently, silica fume concrete (SFC) has become a cost-effective alternative.[3,4] The three main advantages associated with SFC over LMC are (1) the ability to use readily available ready-mixed concrete trucks for mixing rather than the more expensive mobile mixers required for LMC; (2) a lower material cost; and (3) the development of higher early and ultimate strengths for the same water–cementitious material ratio (W/CM). The main advantage of LMC is the total control the contractor has over the production of the concrete without delays in delivery, which can affect the quality of the overlay. LMC and SFC are generally used with a W/CM of 0.40 or less and are placed in accordance with similar procedures.[5] Concretes with high early strength enable the early opening of the roadway to traffic, minimizing inconvenience to the public.

Another low-permeability concrete that was available at the start of this project (but not at its conclusion) was Pyrament-blended cement concrete (PBCC) manufactured by Lone Star Industries, Inc. The W/CM of PBCC was very low (maximum 0.29). PBCC developed very high early strengths even in cold weather, making the roadway available to traffic within a few hours.[6] Another advantage of PBCC (which also applies to LMC) was that it is not air-entrained during batching. This characteristic in field concrete is very beneficial, since the achievement of the proper air content, and its measurement, can often be difficult.

PURPOSE AND SCOPE

The objective of this study was to evaluate and compare the properties of LMC, SFC, and PBCC in thin overlays under field conditions. The minimum thickness for LMC and SFC was 32 mm (1¼ in) and for PBCC was 50 mm (2 in). Two bridges in Virginia were overlaid; in one on I-64, LMC and SFC were used; in the other on primary Rte. 20, PBCC was used. The condition of the decks was evaluated after different intervals of service.

METHODOLOGY

Latex-Modified and Silica Fume Concretes

The bridge on I-64 over Rte. 105 at Newport News carrying the eastbound traffic was isolated by barriers along the middle. One half, including the entrance lane and shoulder, was overlaid on April 23, 1991. The other half, including the traffic and passing lanes, was overlaid on May 7, 1991.

The bridge has three spans. The middle span is 24.4 m (80 ft) long, and the two end spans are each 14.0 m (46 ft) long. The approach slab on each end is about 6.7 m (22 ft) long, and the bridge is 17.1 m (56 ft) wide. The approach slab and adjacent span on the west end were overlaid with SFC, and the remaining spans and approach slab were overlaid with LMC.

Materials and Proportions

Type II cement from the same plant was used in both LMC and SFC. Latex was added in liquid form, and SF in a dry densified form in bags. The coarse aggregate in LMC was No. 8 crushed stone, and in SFC was No. 7 gravel. The fine aggregate in both concretes was siliceous river sand from the same source. Table 1 shows the mixture proportions. The slump requirement for LMC was 100 to 150 mm (4 to 6 in) and for SFC was 150 ± 50 mm (6 ± 2 in). The air content requirement for LMC was 5 ± 2%, and for SFC was 7 ± 2%.

Table 1. Mixture Proportions (kg/m^3)

Ingredient	LMC	SFC	PBCC
Cement	388	375	555
Fine Aggregate	925	753	706
Coarse Aggregate	722	908	985
W/CM	0.38	0.40, 0.36[a]	0.25
Latex Solids	58		
SF		30	

[a] Fine aggregate was increased to 779 kg/m^3.

Placement of Overlay

The surface of the old deck was milled to a depth of at least 18 mm (¾ in). Deteriorated concrete remaining after milling was removed by jack hammers. The reinforcing steel was exposed at the transverse joints and at some deteriorated areas on the deck.

On the day before placement, the exposed reinforcing bars and surface of the base concrete were cleaned by sand blasting. The concrete surface was wetted and covered with plastic sheeting. During placement, the sheeting was removed and the surface, if dry, was wetted again without leaving freestanding water.

LMC was mixed in a mobile mixer at the job site, and SFC was batched in truck mixers at a ready-mix concrete plant about 25 min away from the bridge. To improve bonding, a small amount of concrete was deposited on the base concrete and scrubbed on the surface. The mortar fraction of the concrete provided the bonding layer, and the coarse aggregates were discarded. The concrete was deposited immediately thereafter and was consolidated and screeded with a vibratory screed. At the edges, where the roller screed could not reach, the concrete was consolidated by immersion-type vibrators, and hand floats were used to level the surface. Behind the screed, the LMC overlay was sprayed with a latex emulsion and the SFC overlay with a monomolecular film. Then, wet burlap was applied for moist curing. Virginia Department of Transportation (VDOT) specifications stipulate that LMC be moist cured for 2 days and air dried for 2 days, whereas SFC is to be moist cured for 3 days and then sprayed with a curing compound. Because a weekend intervened, the concretes were moist cured for 4 days. After moist curing, the SFC was sprayed with a curing compound.

Tests

On each of the 2 days of placement, four batches of concrete were tested, two SFC and two LMC, to determine the characteristics of the freshly mixed concrete. Specimens were made to test the compressive strength and permeability of the hardened concrete. A sample was obtained from each of two mobile mixers. On the first day, additional specimens were made to test for flexural and bond strength, freeze-thaw durability, and resistance to chloride penetration by the ponding test. The first batch of SF delivered to the job site had a low air content (3.7%) and was not used on the deck, but specimens were made to determine the strength development under different curing conditions.

At the freshly mixed state, the air content (ASTM C231, pressure method), slump (ASTM C143), air and concrete temperatures, and relative humidity were measured.

Cylinders measuring 100 by 200 mm (4 by 8 in) were prepared and tested for compressive strength at 1, 7, and 28 days in accordance with AASHTO T22 except that neoprene pads in steel end caps were used for capping. Cylinders measuring 100 by 200 mm (4 by 8 in) were also used to determine the rapid chloride permeability (AASHTO T277 or ASTM 1202) at 28 days and at 1 year. The top 50 mm (2 in) of cylinders was tested.

Permeability samples were moist cured for 2 weeks, air dried for 2 more weeks, and tested at 28 days. For the 1-year tests, all LMC and some SFC samples were stored in the laboratory air after the 2-week moist curing, and some SFC samples were moist cured for the total period. Resistance to chloride penetration was also determined using the ponding test (AASHTO T259). Slabs measuring 0.3 by 0.3 m (1 by 1 ft) were cast, cured (2 weeks moist and 4 weeks air dried), ponded with 3% NaCl solution, and tested after 15 months of ponding.

For flexural strength, beams measuring 75 by 75 by 285 mm (3 by 3 by 11¼ in) were tested in accordance with ASTM C78. For bond tests, cylindrical samples 100 mm (4 in) in diameter representing bridge deck concretes that were cast at least 1 month earlier and cut to 50 mm (2 in) height were overlaid with 50 mm (2 in) of LMC or SFC. The interface was subjected to shear stresses, and the overlays were placed on dry cut surfaces. This differs from the procedure used in the field, but the laboratory tests were expected to provide conservative bond values. In the field, the rough base concrete surface was wetted and scrubbed with mortar.

To determine freeze-thaw durability, beams measuring 75 by 100 by 400 mm (3 by 4 by 16 in) were tested using Procedure A of ASTM C666 except that the test water contained 2% NaCl and the samples were moist cured for 2 weeks and air dried for at least 1 week before testing. The acceptance criteria for satisfactory freeze-thaw durability are that the average of three specimens at 300 cycles indicate a weight loss (WL) of 7% or less, a durability factor (DF) of 60 or more, and a surface rating (SR) determined in accordance with ASTM C672 of 3 or less.

All specimens containing SFC tested for strength were moist cured until testing except the rejected first batch. For this batch, in addition to moist curing, samples were cured in the outdoor exposure area or the laboratory air after the initial 7-day moist cure. These specimens were tested at 28 days, 6 months, 1 year, and 3 years, and the ones kept outdoors or in the laboratory air were soaked in water for 48 hr before testing. LMC specimens were kept in the laboratory air after the initial standard moist curing period of 2 days.

Each test value was an average of two specimens for the rapid chloride permeability and drying shrinkage tests and of three specimens for the remaining tests except the ponding test. For the ponding test, pulverized samples were obtained with a 29 mm (1⅛ in) diameter bit at different depths from one slab.

Pyrament-Blended Cement Concrete

The contractor chose to use PBCC to overlay the bridge on Rte. 20 over the Hardware River in Albemarle County. It has three spans and is 60.2 m (198 ft) long and 6.7 m (22 ft) wide. Initially, PBCC was planned for use on I-64 along with LMC and SFC; however, because of concerns regarding potential alkali-silica reactivity with the locally available reactive siliceous aggregates, the less traveled bridge on Rte. 20 was chosen for investigation. VDOT requires the use of non-polishing siliceous aggregates in wearing courses. Between February 5, 1991, and March 28, 1991, first the northbound lane and then the southbound lane were overlaid with PBCC in small 3.0 by 3.4 m (10 by 11 ft) segments. The placement of concrete in segments was dictated by traffic control requirements that permitted lane closure only from 8 a.m. to 5 p.m.

Materials and Proportions

A compressive strength of 17.2 MPa (2,500 psi) was specified for lane opening. Because of the time constraints, PBCC was proportioned to develop this strength in 4 hr even in cold weather. The cement used was PBC-XT, which has an initial setting time of 90 min. As a result of trial batching at the plant and extensive testing in the laboratory, the proportions given in Table 1 were used in 23 batches at the deck. A total of 24 batches delivered and the first batch had different proportions. No. 7 granite gneiss was used as the coarse aggregate, and siliceous river sand was used as the fine aggregate. A large amount of cement, 555 kg/m^3 (940 lb/yd^3) of PBC-XT, was used to achieve slumps of 75 to 100 mm (3 to 4 in) at a maximum w/c of 0.25. In the first batch, 499 kg/m^3 (846 lb/yd^3) of PBC-XT was used and a slump of 57 mm (2¼ in) was achieved at a W/CM of 0.31. This concrete developed 11.3 MPa (1,640 psi) at 10 hr, which was 66% of the strength specified for lane opening, and 8 MPa (1,160 psi) at 4 hr when it was opened to traffic, a strength well below the 17.2 MPa (2,500 psi) specified for opening. In subsequent batches, great care was taken to meet the maximum W/CM of 0.25 to meet the early strength requirements.

Pyrament cement was very sensitive to water. Large changes in unhardened and hardened properties occurred with small additions of water. There was also evidence that the shelf-life is critical since some of the trial batches did not develop the desired high early strength with PBC stored for an extended time.

Placement of Overlay

Usually, two segments were placed each day, and concrete was delivered to the job site in ready-mixed concrete trucks. The job site was 14.5 km (9 mi), about 20 min, away from the plant. The deteriorated concrete was removed by a jack hammer to just below the level of the steel. The reinforcing bar and the surface of the base concrete were cleaned by sand blasting. The surface of the base concrete was wetted, and the PBCC was placed. The concrete was vibrated with immersion-type vibrators and screeded with a simple customized screed consisting of two metal boards vibrated by a small engine. Surface blemishes were hand finished, and a metal tine was used for texturing. The surface was sprayed with a monomolecular film as needed, and then with a curing compound.

Tests

At the freshly mixed state, the slump and the air and concrete temperatures were measured. The temperature development on different days of placement with varying temperatures was monitored by inserting a thermocouple at half-depth in the middle of slabs measuring 0.5 m by 0.5 m by 75 mm (1.5 ft by 1.5 ft by 3 in). One slab was used at a time and was kept near the bridge. The air content was not measured in the field since no air is entrained and the content was about 3.5% in the laboratory mixtures.

For compressive strength tests, cylinders were tested at 3, 4, and 5 hr, and for some batches at 24 hr and 28 days. Specimens were tested for flexural and bond strengths and rapid chloride permeability at 28 days. For drying shrinkage, beams measuring 75 by 75 by 285 mm (3 by 3 by 11¼ in) from 2 batches were tested in accordance with ASTM C157. To determine freeze-thaw durability, beams from two batches were tested. All the specimens were cured air dry following the initial moist curing period during which they were covered by plastic until a strength of 17.2 MPa (2,500 psi) was developed, about 3 to 4 hr. The only exceptions were one of the two batches of specimens tested for drying shrinkage, which were moist cured for 1 month, and the slabs for temperature development, which were sprayed with a curing compound.

Evaluations of Bridge Decks

After construction, cover depth was determined using a device that generates an electric field that is affected by the presence of reinforcing steel. The bridge decks were evaluated immediately after placement of the overlay and after the first and fourth winters. Visual surveys were conducted for cracking and scaling. Chain drag and hammer soundings were used to detect delaminations. Electrical half-cell potentials (ASTM C876) at the 1.2 m (4 ft) grids were measured for corrosion activity. In this test, when the half-cell potentials are more positive than -0.20 volts, there is a 90% probability that no corrosion of the reinforcing steel is occurring; between -0.20 and -0.35 volts, the occurrence of corrosion is uncertain. With values more negative than -0.35, there is a 90% probability that corrosion is occurring. Chloride contents were determined after the fourth winter.

RESULTS AND DISCUSSION

Latex-Modified and Silica Fume Concretes

Freshly Mixed Concretes

Table 2 gives the characteristics of the freshly mixed concretes. The air temperatures ranged from 13 to 16 C (55 to 60 F), and the concrete temperature from 18 to 21 C (65 to 69 F)

Table 2. Characteristics of Freshly Mixed LMC and SFC

Batch No.	Concrete	Air Content (%)	Slump (mm)	RH (%)	Air Temp. (C)	Concrete Temp. (C)
1	SFC	6.8	165	88	13	20
2	SFC	7.8	185	87	13	18
3	LMC	3.3	220	81	13	19
4	LMC	3.8	115	74	16	21
5	SFC	7.6	180	72	18	22
6	SFC	8.2	130	65	18	23
7	LMC	3.5	120	55	20	23
8	LMC	3.4	140	52	23	24

during the preparation of the samples on the first day of placement. The air and concrete temperatures were higher on the second day of placement. The air temperature ranged from 18 to 23 C (64 to 74 F), and the concrete temperature from 22 to 24 C (72 to 76 F). The air contents were all within the specification. Slumps were generally above 125 mm (5 in), which made it easy to level and finish with the roller screed.

Compressive Strength

The compressive strengths are given in Table 3 and depicted in Figure 1. All strengths were satisfactory. On the first day of placement, the 1-day compressive strength of SFC was slightly above 14 MPa (2,000 psi), which was less than the expected value of 24 MPa (3,500 psi) or more for the reported W/CM of 0.40.[5] The producer lowered the W/CM to a reported value of 0.36 for the second day of placement, and 1-day strengths increased to about 28 MPa (4,000 psi), which is more than the 24 MPa (3,500 psi) needed for opening to traffic. The 1-day strength for LMC ranged from 14.5 to 18.6 MPa (2,110 to 2,700 psi).

The compressive strengths of specimens from the rejected batch of SFC (low air content) subjected to different curing conditions are given in Table 4 and depicted in Figure 2. The results showed that strength increased or leveled off when SFC was kept in the moist room or outdoors but decreased or did not change when kept in the dry laboratory air, which can be attributed to drying shrinkage.[7]

Table 3. Compressive Strengths of LMC and SFC (MPa)

Batch No.	Concrete	W/CM	1 Day	7 Days	28 Days
1	SFC	0.40	15.4	34.1	50
2	SFC	0.40	14.5	32.5	43
3	LMC	0.38	14.5	28.3	39
4	LMC	0.38	16.3	32.5	43.7
5	SFC	0.36	29.4	47.0	62.3
6	SFC	0.36	27.0	42.6	56.7
7	LMC	0.38	17.8	23.3	38.3
8	LMC	0.38	18.6	24.1	38.1

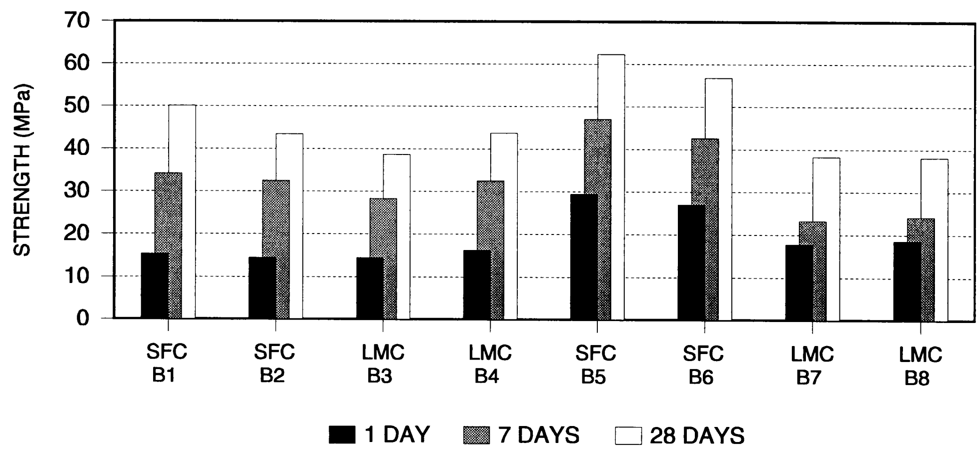

Figure 1. Compressive Strength of SFC and LMC at 1, 7, and 28 Days

Table 4. Compressive Strength of SFC Under Different Curing Conditions (MPa)

Age	Moist Room	Lab Air	Outdoors
7 days	37.9	-	-
28 days	56.7	53.5	56.5
6 mo	65.2	46.8	59.6
1 yr	67.8	46.4	63.5
3 yr	---	44.3	62.1

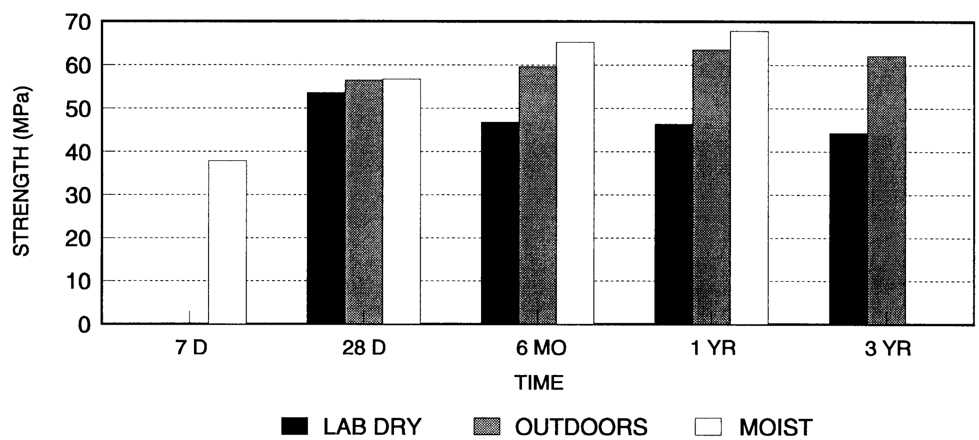

Figure 2. Compressive Strength of SFC Under Different Curing Conditions

Flexural and Bond Strengths

The flexural and bond strengths at 28 days are given in Table 5 and depicted in Figure 3. Bond strengths were higher for SFC than LMC, but flexural strengths were lower. However, all strengths for both types of concrete were satisfactory.

Table 5. Flexural and Bond Strengths of LMC and SFC at 28 Days

Batch	Concrete	Flexural (MPa)	Bond (MPa)
1	SFC	4.9	4.0
2	SFC	4.3	5.4
3	LMC	6.2	2.2
4	LMC	6.6	2.2

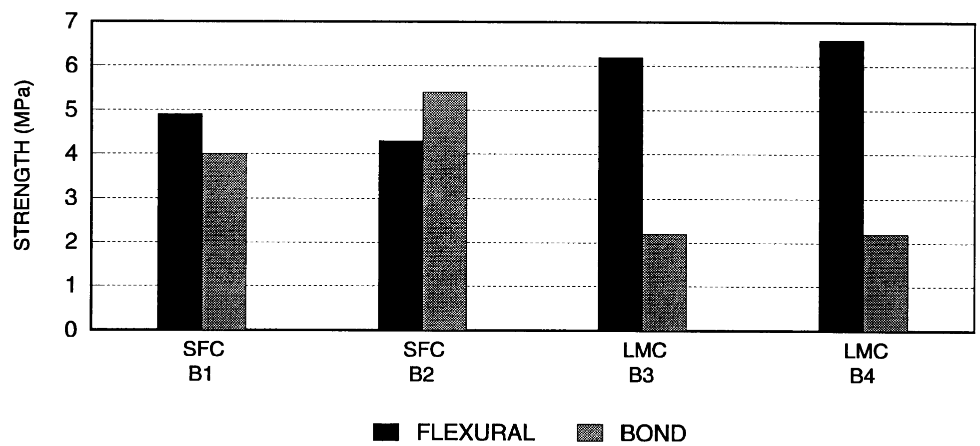

Figure 3. Flexural and Bond Strength of SFC and LMC at 28 Days

Permeability

The permeability values are given in Table 6 and depicted in Figure 4. They indicate that at 28 days, very low permeability (≤1,000 coulombs) can be obtained with SFC and a low permeability (≤2,000 coulombs) can be obtained with LMC. At 1 year, a more rapid reduction in permeability occurred in LMC. Thus, both concretes had very low permeability.

An exception to this trend was one batch of SFC that had moderate permeability at the beginning that was higher than expected (and a strength lower than expected) and did not attain the very low permeability rating at 1 year. The proportions used by VDOT are expected to result in permeability values at or close to the very low range (≤1,000 coulombs) at 28 days.[5] The results clearly indicate that care should be exercised to properly proportion, batch, and place concretes so that the very low permeability desired can be obtained.

Table 6. Permeability of LMC and SFC

Batch	Concrete	28-Day Permeability (coulombs)	1-Year Permeability (coulombs)
1	SFC	1575	736 MC; 1902
2	SFC	2369	1137 MC; 3062
3	LMC	1967	208
4	LMC	1636	158
5	SFC	633	440 MC
6	SFC	750	469 MC
7	LMC	1608	369
8	LMC	2021	331

All samples were air dried after 2 weeks of moist curing except the ones designated "MC," which were only moist cured.

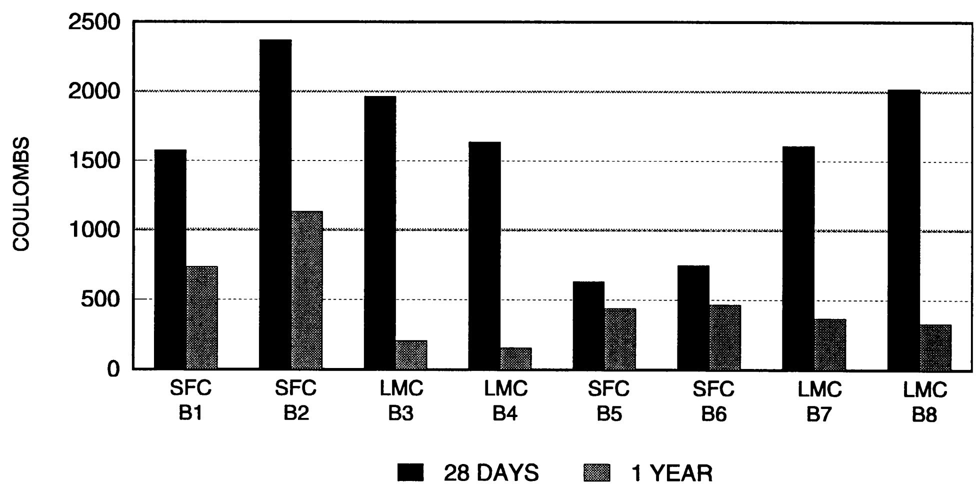

Figure 4. Permeability of SFC and LMC at 28 Days and 1 Year

The SFC kept in laboratory air after 2 weeks of moist curing had higher permeability values at 1 year than at 28 days, although they were in the same rating range. Similar results were obtained in the compressive strength testing, where strengths decreased or did not change, indicating the importance of moisture during curing for optimum development of desired properties.

The chloride content after 15 months of ponding is given in Table 7. SFC had a higher chloride content at the 13 and 25 mm (½ and 1 in) depths. However, it had higher coulomb values and lower compressive strength than expected. In any case, the chloride content was negligible at 38 mm (1½ in) and deeper after 15 months of ponding, indicating the high resistance provided by LMC and SFC.

Table 7. Chloride Content of SFC and LMC (kg/m^3)

Batch	Concrete	13 mm	25 mm	38 mm	51 mm
1	SFC	6.80	0.83	0.00	0.00
2	SFC	10.13	1.53	0.00	0.00
3	LMC	5.91	1.03	0.00	0.00
4	LMC	2.60	0.19	0.02	0.00

Freeze-Thaw Durability

Table 8 gives the freeze-thaw durability for LMC and SFC. SFC had satisfactory durability, but LMC did not. However, the field performance of LMC has been satisfactory, indicating that the low permeability of LMC makes it difficult to saturate in bridge decks, thus preventing deterioration from freezing and thawing in the field.

Table 8. Freeze-Thaw Durability of LMC and SFC

Batch	Concrete	Weight Loss (%)	Durability Factor	Surface Rating (ASTM C672)
1	SFC	1.8	98	2.1
2	SFC	1.8	99	2.2
3	LMC	16.9	23	5.0
4	LMC	10.1	38	3.7

Pyrament-Blended Cement Concrete

Freshly Mixed Concretes

Table 9 provides the characteristics of freshly mixed PBCC for 23 batches, and Figure 5 displays the temperatures. The slumps varied from 55 to 120 mm (2¼ to 4¾ in), with an average value of 85 mm (3.3 in). Air temperature varied from 0 to 24 C (32 to 75 F) at the beginning of each placement operation. Sometimes at night, the temperature dropped well below freezing. The initial temperature of the concrete was kept above 16 C (60 F) by the addition of mixing water at a temperature of 66 C (150 F) during cold weather. The temperatures developed within PBCC for the temperature extremes encountered are shown in Figure 6 for a cool day and Figure 7 for a warm day. The rise in temperature occurred at about 2.5 hr in cool weather and a little after 1 hr in warm weather. Thus, there was a retardation of the hydration reactions in cool weather.

Table 9. Characteristics of Freshly Mixed PBCC

Batch	Slump (mm)	W/C	Temperature ©	
			Air	Conc
1	65	0.25	--	22
2	65[a]	0.24	7	20
3	75[a]	0.24	0	17
4	55	0.24	17	29
5	70[a]	0.25	16	30
6	70[a]	0.25	20	21
7	90[a]	0.25	9	20
8	115	0.24	14	24
9	95	0.25	18	22
10	--	--	11	--
11	90[a]	0.25	12	26
12	75	0.24	12	24
13	85	0.24	7	21
14	110[a]	0.25	6	24
15	--	--	11	--
16	120	0.24	--	22
17	95	0.25	12	23
18	90	0.24	15	28
19	--	--	--	--
20	85[a]	0.25	14	24
21	--	--	17	24
22	70[a]	0.25	24	27
23	--	--	--	--

[a]Water was added after the slump test. The final W/C is shown.

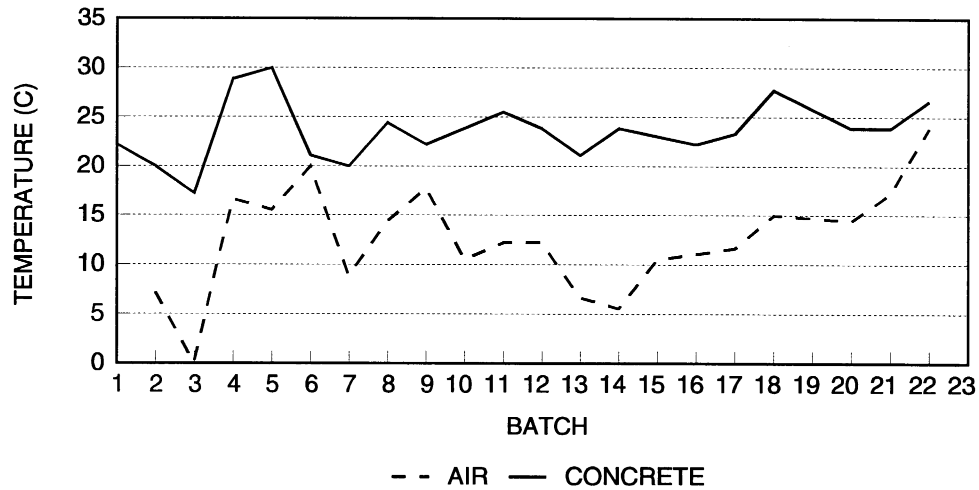

Figure 5. Air and Concrete Temperatures for PBCC

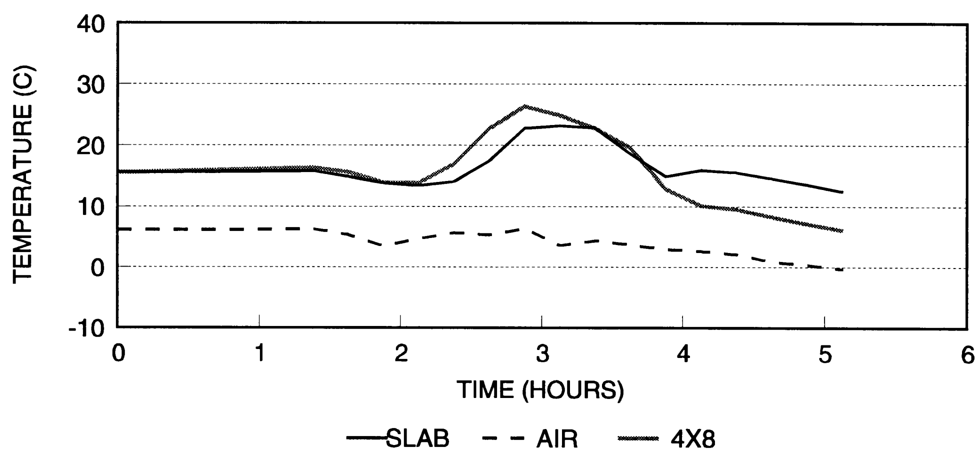

Figure 6. Temperature Development of PBCC at Low Ambient Temperatures

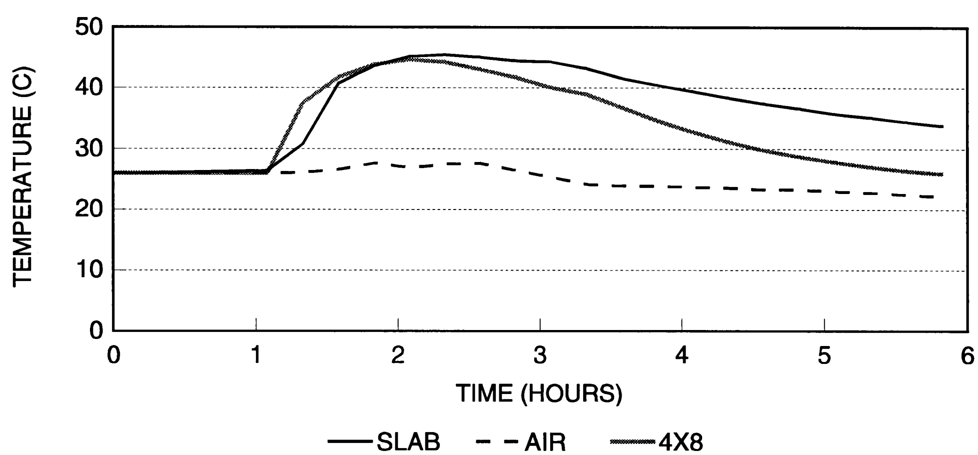

Figure 7. Temperature Development of PBCC at Moderate Ambient Temperatures

Compressive Strength

Compressive strengths are given in Table 10 and depicted in Figure 8. In most batches, 17.2 MPa (2,500 psi) was achieved in 4 hr, and in many, in 3 hr. The concretes placed in warm weather developed higher early strengths, which is mainly attributable to the early setting time and temperature rise.

Table 10. Compressive Strength of PBCC (MPa)

Batch	3 Hr	4 Hr	5 Hr	24 Hr	28 Days
1	13.9	17.7	19.9	27.2	70.8
2	8.7	16.6	19.2		
3	6.7	11.6	19.7	25.8	72.9
4	20.1	22.1	23.1	37.5	79.3
5	14.3	16.7	17.2		
6	15.4	18.8	19.9		
7	6.2	18.4	22.1		
8	15.9	19.6	20.6	30.8	78.6
9	13.0	16.0	17.2		
10	15.3	22.0	25.2		
11	16.8	18.8	20.0		
12	18.1	20.3	22.1		
13	11.4	20.8	23.4		
14	14.5	21.3	23.6		
15	18.7	23.0	25.2	33.8	83.4
16	17.5	20.5	23.9		
17	18.4	23.8	26.1		
18	16.7	20.3	21.5		
19	19.3	--	--	43.4	78.6
20	17.6	21.0	22.3		
21	19.4	21.0	22.6		
22	20.9	23.7	25.9	44.3	80.4
23	13.4	19.0	20.7		

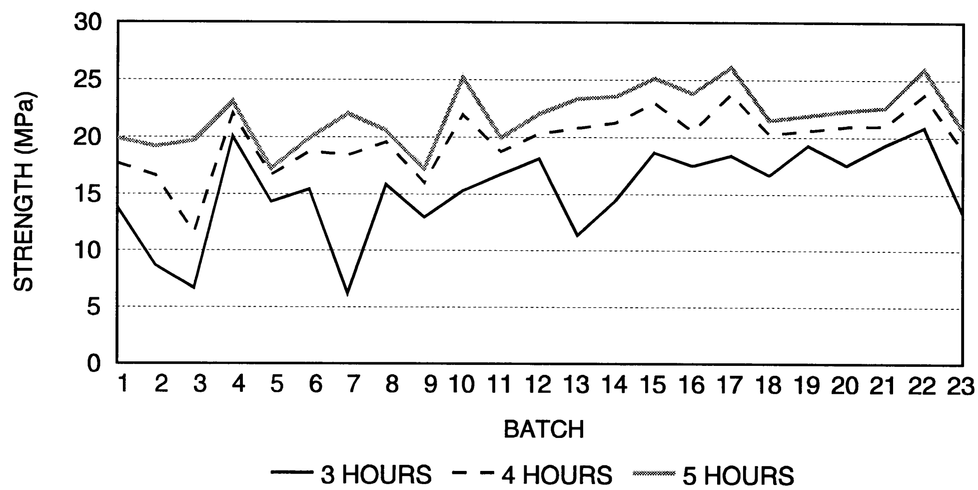

Figure 8. Very Early Compressive Strength of PBCC

Flexural and Bond Strengths

Table 11 shows the flexural and bond strengths. Satisfactory strengths can be attained at early ages.

Table 11. 28-Day Flexural and Bond Strengths of PBCC (MPa)

Batch	Flexural			Bond		
	3 hr	4 hr	28 days	3 hr	4 hr	28 days
8	---	2.8	4.8	---	1.2	4.9
15	2.3	---	5.8	1.6	---	3.3

Drying Shrinkage

Table 12 gives the drying shrinkage values based on an initial reading at 24 hr. The specimens cured for 28 days in the moist room shrank less than those cured under the plastic sheeting for 3 hr and then air dried. In comparison to the bridge deck concrete regularly used, which is usually expected to shrink about 0.07% after 1 year when moist cured for 28 days and then air dried, the specimens moist cured for 28 days had less shrinkage, but those air dried after 3 hr had more shrinkage.

Table 12. Length Change of PBCC (%)

Batch	Cure	4 wk	8 wk	1 yr
8	Air dry[a]	0.027	0.035	0.095
15	Moist[b]	0	0.005	0.018

[a]After 3 hr of cure under plastic sheeting. Ages are after batching. Length change is based on an initial reading at 24 hr.
[b]After 28 days of moist curing and then air dried. Ages are after the moist cure period. Length change is based on an initial reading at 24 hr.

Permeability

The rapid chloride permeability values at 28 days were 1,214 coulombs for one batch, B8, and 1,138 coulombs for the other batch, B15, indicating low permeability.

Freeze-Thaw Durability

The data in Table 13 indicate that freeze-thaw durability was satisfactory.

Table 13. Freeze-Thaw Durability of PBCC

Batch	Weight Loss (%)	Durability Factor	Surface Rating (ASTM C672)
8	0.3	95	0.3
15	0.5	94	0.8

Evaluations of Bridge Decks

Latex-Modified and Silica Fume Concretes

Initial Evaluation

Evaluation of the deck after placement revealed no cracks and no delaminations. The cover depths are given in Table 14. Average values exceeding 64 mm (2.5 in) were obtained, and the cover depth was about 12 mm (0.5 in) deeper on the half with the shoulder and entrance

Table 14. Cover Depth for LMC and SFC

Span	Concrete	Lane	Average (mm)	Std. Dev. (mm)
1	SFC	SE	78	11
1	SFC	TP	65	6
2	LMC	SE	76	8
2	LMC	TP	66	6
3	LMC	SE	78	8
3	LMC	TP	66	7

SE = Shoulder and entrance lanes.
TP = Traffic and passing lanes.

lane. It is expected that the minimum overlay thickness of 32 mm (1¼ in) was maintained on the deck. The initial half-cell potential values are given in Table 15, representing the three ranges indicative of the presence, absence, or uncertainty of corrosion. It appeared that corrosion was occurring in some areas. There were also large areas with uncertain corrosion activity.

Table 15. Percentage Distribution of Half-Cell Potentials for LMC and SFC Overlays

Span	Lane	> -0.20 V			-0.20 to -0.35 V			< -0.35 V		
		1991	1992	1995	1991	1992	1995	1991	1992	1995
1 (SFC)	SE	1	93	90	72	7	10	27	0	0
	TP	1	100	100	92	0	0	7	0	0
2 (LMC)	SE	62	56	71	35	44	29	3	0	0
	TP	36	87	43	63	13	57	2	0	0
3 (LMC)	SE	51	70	89	47	30	11	2	0	0
	TP	19	92	51	73	8	49	8	0	0

SE = Shoulder and entrance lanes.
TP = Traffic and passing lanes.

First Winter

The deck was evaluated again after the first winter, on June 29, 1992. There were no delaminations, but there were many cracks, most of them very tight. Most were on the traffic and passing lanes of the first span, S1, with SFC, and on the shoulder area with LMC. The W/CMs of SFC in the traffic and passing lanes were lower than on the other shoulder and entrance lanes. Cracks were random and longitudinal. Some were perpendicular to the joints, especially in the SFC overlay. There were few tight cracks in the entrance lane with SFC, and very few in the shoulder area with SFC. LMC had few cracks in the entrance lane at the midspan and very few in the entrance lane of the end span and all of the traffic and passing lanes. The half-cell potentials indicated the absence of corrosion. There were areas where corrosion activity was uncertain, but most of the deck area was corrosion free. Corrosion activity appeared to be reduced compared to the previous year.

Fourth Winter

The deck was evaluated again after the fourth winter, on April 26, 1995. In span S1 where SFC was used, there were many cracks, more than observed after the first winter. Most were tight and were longitudinal or random. Three longitudinal cracks were continuous throughout the span. Spans S2 and S3 with LMC had much less cracking, which was longitudinal and shorter than in span S1. The cracks emphasize the importance of proper curing. For proper curing, a power sprayer is needed that can provide fine misting and thorough coverage of the surface. LMC was sprayed with a latex emulsion, which may have been more effective in preventing drying during early curing than the monomolecular film sprayed on the SFC.

There were no delaminations, and scaling was none to very light on all spans. The half-cell potentials indicated no corrosion activity. However, there were areas where corrosion activity was uncertain. The percentage of uncertain areas was higher in spans S2 and S3 where LMC was used. Compared to the previous year, the areas with uncertain corrosion activity had decreased in the shoulder and entrance lanes but increased in the traffic and passing lanes. Uncertain areas basically remained the same in SFC.

The chloride content was determined at three average depths of 13 mm (0.5 in), 25 mm (1 in), and 38 mm (1.5 in) and is given in Table 16. Each average depth represents a pulverized sample obtained in a thickness of 13 mm (0.5 in) with a drill bit. The chloride content sufficient to initiate corrosion, known as the threshold value, is about 0.77 kg/m^3 (1.3 lb/yd^3). All values at 13 mm (0.5 in) and 25 mm (1 in), except one value at 13 mm, were below the threshold value. At 38 mm (1.5 in), values were higher than at 25 mm (1 in), indicating the base concrete was reached.

The overall results indicated no certainty of corrosion activity and low chloride contents in the overlay. Thus the LMC and SFC overlays are performing as desired.

Table 16. Chloride Content for LMC and SFC Overlays (kg/m³)

No.	Span	Lane	Wheel Path	13 mm	25 mm	38 mm
1	1	TP	Y	0.27	0.50	0.90
2	1	TP	N	0.37	0.14	0.53
3	1	SE	N	0.23	0.13	0.28
4	1	SE	Y	0.81	0.27	1.07
5	2	SE	N	0.52	0.12	0.56
6	2	TP	N	0.62	0.15	0.30

SE = Shoulder and entrance lanes.
TP = Traffic and passing lanes.

Pyrament-Blended Cement Concrete

Initial Evaluation

After placement operations, cracks were observed on most segments, and separation between segments was visible. The contractor treated the surface with high-molecular-weight methacrylate acrylic (HMWM) to seal the cracks. There were no delaminations. The average cover depth and half-cell potentials were determined for the end span, S1, from the north end and the adjacent section of the middle span, S2, along the southbound lane. The cover depth was 70 $\pm$ 4 mm (2.81 $\pm$ 0.16 in) on S1 and 54 $\pm$ 5 mm (2.14 $\pm$ 0.21 in) on S2. The half-cell potentials given in Table 17 show that corrosion activity was occurring in the entire area.

Table 17. Percentage Distribution of Half-Cell Potentials of PBCC Overlay

Span	Lane	> -0.20 V			-0.20 to -0.35 V			< -0.35 V		
		1991	1992	1995	1991	1992	1995	1991	1991	1995
1	SBL	0	0	2	0	23	35	100	77	63
2	SBL	0	0	0	0	29	73	100	71	27

First Winter

Span S1 and 15 m (50 ft) of span S2 were evaluated after the first winter, on October 16, 1992. Two delaminations were detected along the joints between segments: one about 200 by 300 mm (8 by 12 in) and the other 300 by 400 mm (12 by 16 in). Very few additional cracks were noticed. Half-cell potentials indicated that the area with corrosion activity had decreased.

Fourth Winter

The same deck area was evaluated after the fourth winter, on May 9, 1995. Two new small delaminated areas along the joint measuring 8 by 8 mm (3 by 3 in) were detected, but the previously detected delaminated areas were not noticed. There was very little additional cracking. Half-cell potentials showed a further reduction in the area with corrosion activity. The chloride content was determined at three locations, and the results given in Table 18 indicate that it was low and negligible below 25 mm (1 in). The low chloride content could be due to the HMWM treatment, but PBCC also had low coulomb values.

Table 18. Chloride Content for PBCC Overlay

No.	Wheel Path	13 mm	25 mm	38 mm
1	Left	0.39	0.00	0.00
2	Right	0.28	0.00	0.00
3	Center	0.42	0.10	0.01

The overall results indicated that corrosion activity was slowing and the penetration of chlorides was reduced. Thus, the overlay is performing satisfactorily.

CONCLUSIONS

1. LMC, SFC, and PBCC provide satisfactory ultimate strengths. PBCC develops high very early strengths, and SFC develops sufficient compressive strength for opening to traffic in 1 day. All three concretes develop adequate flexural and bond strength.

2. SFC develops a very low permeability at 28 days, whereas LMC and PBCC develop a low permeability at 28 days. LMC has a high rate of permeability reduction and at 1 year has very low permeability, lower than that of SFC even though permeability is also reduced with SFC with time. Both LMC and SFC develop very low permeability at later ages.

3. SFC and PBCC have adequate freeze-thaw durability, but LMC does not. However, field experience shows that LMC provides satisfactory freeze-thaw durability.

4. LMC, SFC, and PBCC are prone to shrinkage cracks. Proper and immediate curing are essential.

5. LMC, SFC, and PBCC have a high resistance to chloride penetration.

6. Half-cell potential values indicate a reduction in corrosion activity compared to that immediately after placement.

RECOMMENDATIONS

- SFC, LMC, and PBCC can be used in thin overlays to prevent the penetration of chlorides or other aggressive solutions.

- PBCC can be used in cold weather and when high early strengths exceeding 17.2 MPa (2,500 psi) are needed in about 4 hr or more. However, the use of PBCC with reactive aggregates should be avoided or closely monitored until further data on alkali-silica reactivity are available.

- SFC can be used when traffic flow is required in 1 day.

- These concretes have a low W/CM and low bleeding characteristics, making them prone to plastic shrinkage. Proper construction practices, especially proper curing methods, must be followed to obtain the desired concrete properties.

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