High Early Strength Latex-Modified Concrete Overlay

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This paper describes the condition of the first high early strength latex-modified concrete (LMC-HE) overlay to be constructed for the Virginia Department of Transportation. The overlay was prepared with type III cement and with more cement and less water than is used in the conventional latex-modified concrete (LMC) overlay. Tests of the bond and compressive strength of the LMC-HE overlay performed during the first 24 hr after installation indicated that traffic could be placed on the overlay within 24 hr rather than the 4–7 days required for the conventional LMC overlay. Tests of the bond strength and permeability to chloride ion conducted after 1 yr in service indicate that the overlay is performing satisfactorily. Pending continuing favorable test results, it is anticipated that LMC-HE overlays can be used in situations in which it is desirable to accelerate construction, to reduce inconvenience to motorists, to allow for installation during off-peak traffic periods such as weekends, to provide a more rapid cure in cold weather, to provide low permeability (compared to concrete without latex), and to provide high strength, particularly, high early strength.

Latex-modified concrete is a portland cement concrete in which an admixture of latex emulsion is used to replace a portion of the mixing water. This type of concrete, which has been used on highway bridges over the past 25 yr (*1*), was first used on a bridge deck in Virginia in 1969 (*2*).

The Virginia Department of Transportation's special provision for LMC overlays requires 3.5 gal of styrene butadiene latex emulsion (46.5–49.0 percent solids) per bag of cement (*3*). Other Department requirements are a minimum cement content of 658 lb/yd^3; a maximum water content of 2.5 gal per bag of cement; a water-cement ratio (w/c) of 0.35–0.40; an air content of 3–7 percent; a slump of 4–6 in. when measured 4.5 min after discharge from the mixer; and a cement, sand, coarse aggregate ratio by weight of 1.0/2.5/2.0. By comparison, the requirements for class A4 concrete used in bridge decks include a minimum cement content of 635 lb/yd^3, a maximum w/c of 0.45 (0.47 from 1966 to 1983), an air content of 5–8 percent, and a slump of 2–4 in. (*4*). Thus, it can be seen that by design the LMC is batched with more cement, less water, less air, and at a higher slump.

Compared with A4 bridge-deck concrete, the LMC is reported to be more resistant to the intrusion of chlorides; to have higher tensile, compressive, and flexural strengths; and to provide better freeze-thaw performance (*1*). The greater resistance to chloride intrusion is said to be attributable to the lower w/c and a plastic film which the latex emulsion produces within the concrete and which inhibits the movement of chlorides. The concrete reportedly has a higher strength because the w/c is lower and because the plastic film produces a higher bond strength between the paste and aggregate. Its freeze-thaw performance is said to be superior because the lower permeability helps keep water out of the concrete and because the concrete is more flexible and therefore able to withstand the expansion and contraction associated with frost action (*1*).

The installation of LMC overlays is one of the most popular ways to extend the service life of bridge decks constructed without epoxy-coated reinforcement. The life of the deck is extended because the LMC overlay inhibits the movement of chlorides to the reinforcement and this delays the onset of corrosion.

On occasion, a bridge in need of an overlay cannot be closed to traffic without subjecting the public to significant inconvenience unless the overlay can be installed during off-peak traffic periods. Because of the slow strength development of currently used LMC mixtures, other systems such as polymer or epoxy overlays or penetrating sealers are often applied to these bridges, but current studies are revealing the shortcomings of some of these systems (*5*).

OBJECTIVE

The objective of the research described by this paper was to refine currently used LMC mixtures to allow the installation of a high early strength LMC (LMC-HE) overlay that can be subjected to traffic in less than 24 hr. Once installed, the objective was to monitor the compressive strength, bond strength, and permeability to chloride ion of the LMC-HE overlay.

COOPERATIVE AGREEMENT

A contract for the installation of an LMC overlay was modified to allow the installation of the LMC-HE mixture on a bridge on Rte. 340 over Hawksbill Creek in Rockingham County. The bridge was selected for the experimental installation because of the small surface area (269 yd^3), low traffic volume (ADT = 1,190), and the willingness of the Staunton district bridge engineer (Larry Misenheimer), the contractor (Lanford Brothers Company, Inc.), and the polymer supplier (Dow Chemical U.S.A.) to participate in the installation. Based on two meetings among the contractor, the polymer supplier, the bridge engineer, and the principal investigator, the following responsibilities for conducting the project were agreed upon.

Virginia Transportation Research Council, Box 3817, University Station, Charlottesville, Va. 22903–0817.

Contractor

- Construct LMC-HE overlay that equals or exceeds the requirements for LMC overlays, except as otherwise specified.
- Modify installation equipment (ASTM C 685) and techniques as necessary (no modifications were required).
- Provide necessary materials.
- Calibrate mobile mixer to provide acceptable LMC-HE concrete mixture.

Polymer Supplier

- Assist with the proportioning of the concrete mixture and provide latex.
- Assist with calibration of mobile mixer.
- Recommend necessary modifications to mobile mixer and installation equipment (none were required).
- Provide technical assistance.

Virginia Department of Transportation

- Approve mixture proportions and installation technique.
- Measure compressive strength (ASTM C 39) at early ages (≦24 hr) and at 28 days.
- Measure bond strength at ≦24 hr, 28 days, and 1 yr using guillotine smear apparatus.
- Measure permeability to chloride ions at approximately 1 mo and 1 yr using AASHTO T 277 procedure.
- Measure freeze-thaw performance of specimens of the mixture using ASTM C 666 Procedure A.
- Write report describing the installation (including materials and equipment) and the condition of the overlay initially and at 1 yr.

MIXTURE PROPORTIONS

The LMC-HE mixture used in the overlay was selected after three trial batches (lab mixes 1, 2, and 3) were prepared in the laboratory using the ingredients that would be used in the overlay. Lab mix 1 was prepared after consideration was given to the mixtures that contained type III cement (ASTM C 150) and that were successfully used for patching decks and pavements and in the production of precast prestressed bridge members (*6–8*). Particular consideration was given to the LMC-HE mixture used for deck patching by the Richmond/Petersburg Turnpike Authority and the Michigan Department of Transportation (*6*). Lab mix 1 had a water-to-cement ratio of 0.34, a cement content of 815 lb/yd^3, and a fine-aggregate-to-total-aggregate ratio of 0.47. For lab mix 2, the ratio of fine aggregate to total aggregate was increased to 0.55. For lab mix 3, the water-to-cement ratio was reduced to 0.27, and the cement content was reduced to 681 lb/yd^3. Lab mix 2 was selected for use in the overlays because the mixture exhibited the best properties in the plastic state and produced the desired properties in the hardened concrete.

A comparison of the mixture proportions for typical A4 concrete, typical LMC, and the LMC-HE lab mix 2 is shown in Table 1. The basic differences between the LMC and the LMC-HE mixture are (a) the LMC-HE mixture contains type III cement, whereas the LMC mixture contains type II cement (ASTM C 150); (b) more cement is used in the LMC-HE mixture; and (c) the LMC-HE mixture has a lower w/c. The physical and chemical properties of the cement used in the LMC-HE are shown in Table 2.

INSTALLATION OF LMC-HE OVERLAY

The installation procedure for the LMC-HE overlay was the same as for an LMC overlay. The deck was scarified to remove the top 0.5 in. of the old concrete. In areas that required partial- and full-depth repairs, the concrete was removed with hammers. Twenty-four hours prior to the placement of the overlay, the exposed surfaces of the concrete were sandblasted, sprayed with water, and covered with a sheet of polyethylene. The overlay placements for both the southbound lane (SBL) and the northbound lane (NBL) were scheduled to begin at daybreak.

The concrete for the SBL was placed on May 21, 1986, beginning at 7:00 a.m.; the air temperature was 60°F. The high air temperature for the 24-hr period following the placement was 78°F, and the low was 55°F. The concrete for the NBL was placed on June 19, 1986, beginning at 6:10 a.m.; the air temperature was 48°F. The high air temperature for the 24-hr period following the placement was 85°F and the low was 50°F.

TABLE 1 MIXTURE PROPORTIONS

	A4	LMC	LMC-HE
Cement, lb/yd^3	635	658	815
W/C	0.45	0.37	0.34
Latex, gal/bag	0	3.5	3.0
Air, percent	5-8	3-7	3-7
Fine aggregate, (S.G. = 2.61, F.M. = 3.0), lb/yd^3	1178	1571	1402
Coarse aggregate, (S.G. = 2.51), lb/yd^3	1809	1234	1142

TABLE 2 PHYSICAL AND CHEMICAL PROPERTIES OF CEMENT USED IN LMC-HE (cement type MT-III)

Chemical Analysis		Physical Analysis	
S102	20.82%	Fineness:	
AL203	4.44%	Blaine	5040
(CM2/GM)			
FE203	2.12	Passing #325	99.1%
CAO	62.23%		
MGO	3.24%	Compressive Strength	
S03	4.40%		
Ignition Loss	0.90%	1 Day	3,010 (psi)
Free CAO	0.45	3 Days	4,860 (psi)
NA20 Equiv.	0.69%	7 Days	5,930 (psi)
		28 Days	---

Meets Latest Requirements of ASTM C 150 and AASHTO M 85

The concrete for both lanes was batched and mixed with a concrete mobile (ASTM C 685). The concrete was discharged onto the deck at a slump of about 5–7 in. The mortar fraction of the mixture was brushed onto the surface with coarse-bristle brooms just ahead of the overlay placement. A rotating drum screed was used to consolidate and strike off the concrete except along the parapet, center line, and joints, where immersion-type vibrators and hand floats were required. A tined texture was applied for skid resistance, and wet burlap was applied immediately after the surface was textured. The wet burlap was covered with polyethylene to retain the moisture and to prevent plastic shrinkage cracks.

The overlays were moist-cured for 24 hr, except the last 10 ft of each lane, which were moist-cured for only 12 hr because it was anticipated that the 3,000 psi compressive strength necessary to open the overlay to traffic might be obtained at 12 hr. Rather than waiting the 4–7 days typical for LMC overlays, the NBL was opened to traffic after 24 hr. No cracks were found in either overlay at 24 hr and 28 days. After 1 yr in service, several short longitudinal cracks were observed in the NBL adjacent to the transverse joint between two spans.

RESULTS

Compressive Strength

Cylinders of concrete, 4 in. in diameter by 8 in high, were fabricated and tested in compression using steel end caps and neoprene pads (AASHTO T 22). During the first 24 hr, the specimens were cured in plastic molds with wet burlap on the surface. The specimens from the NBL LMC-HE were cured and tested at the job site for the first 16 hr and those from the SBL LMC-HE for the first 10 hr prior to being transported to the laboratory located approximately 1 hr from the job site. The specimens were removed from the molds at 24 hr and air-cured in the laboratory. The results shown in Table 3 are based on the average of tests on three cylinders for ages of 12 hr, 24 hr, and 28 days and the average of tests on two cylinders for other ages.

A comparison of the compressive strength with age for a standard LMC overlay and the NBL LMC-HE is shown in Figure 1. Four to 7 days are required to obtain the 3,000 psi compressive strength necessary to place traffic on a standard LMC overlay, whereas 3,000 psi was obtained in approximately 21 hr with the NBL LMC-HE mixture.

A comparison of the compressive strength with age for the NBL LMC-HE and lab mix 2 is shown in Figure 2. The strength of the NBL LMC-HE is somewhat lower than the strength of the mixture prepared in the laboratory. A strength of 3,000 psi was obtained in approximately 16 hr with lab mix 2 as compared to 21 hr for the NBL LMC-HE mixture.

A comparison of the compressive strength with age for lab mix 2 and the SBL LMC-HE is shown in Figure 3. A strength of 3,000 psi was obtained in 12 hr with the SBL LMC-HE. The 28-day strengths were about the same for the two mixtures. It is believed that the SBL LMC-HE mixture duplicated lab mix 2 but obtained 3,000 psi sooner because the curing temperature was higher. The cylinders were cured next to the bridge deck, in the sun, under wet burlap and polyethylene, and at a maximum air temperature of 78°F as compared to 73°F in the laboratory.

Shear Bond Strength

Figure 4 shows the guillotine shear apparatus used to collect the shear bond strength data reported in Table 4. A test value was determined by placing a 4-in.-diameter core or specimen into the base, placing the top part of the apparatus over the overlay, and subjecting the apparatus to a compressive force that sheared the overlay from the base concrete. Tests were conducted on cores from the bridge deck and specimens of A4 bridge deck concrete that were overlaid at the job site.

TABLE 3 COMPRESSIVE STRENGTHS

Age	LMC	Lab Mix 2	SBL LMC-HE	NBL LMC-HE
6 hr.	---	---	---	130
7 hr.	120	---	---	320
8 hr.	---	---	---	930
9 hr.	---	---	---	1,520
10 hr.	---	---	---	1,990
11 hr.	---	---	---	2,190
12 hr.	580	2,330	3,000	2,360
14 hr.	---	---	---	2,570
18 hr.	1,150	3,290	---	---
24 hr.	1,570	3,740	4,010	3,190
2 day	2,360	4,330	---	---
7 day	3,360	5,100	5,230	4,650
28 day	4,630	6,210	6,140	5,260

NOTE: Units are lb/in.^{2}.

The results shown in Table 4 are based on the average of tests on three specimens or cores for ages of 12 hr, 24 hrs, 28 days, and 1 yr and the average of tests on two specimens for other ages.

A comparison of the bond strengths with age for specimens prepared with the SBL and the NBL LMC-HE mixtures is shown in Figure 5. As with compressive strength, the bond strength was somewhat higher for the mixture used on the SBL as compared to that used on the NBL.

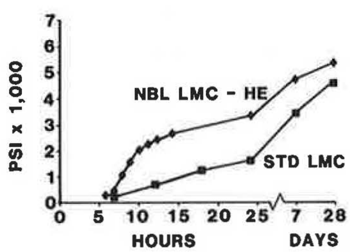

FIGURE 1 Compressive strength vs. age (NBL LMC-HE and STD LMC).

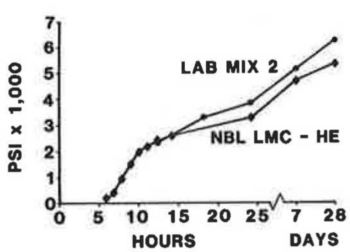

FIGURE 2 Compressive strength vs. age (NBL LMC HE and lab mix 2).

A comparison of the average shear bond strength for both lanes with age for specimens prepared at the job site and cores taken from the deck is shown in Figure 6. The shear bond strengths of the specimens and cores are similar at 24 hr and 28 days. At 12 hr, the average bond strength of the specimens was 350 psi; at 24 hr, 500 psi; and at 28 days, 580 psi. The average shear bond strength of the cores removed and tested at 28 days was 580 psi; and after approximately 1 yr in service, it was 620 psi. The average shear strength of the base concrete was 640 psi.

Figure 7 shows the shear strength data taken from a study done in 1983 in which cores were taken from 12 bridges that had been overlaid with standard LMC over a 13-yr period (*9*). At the time of the evaluation, the overlays ranged in age from 1 yr to 13 yr. Three cores were taken from each overlay and sheared twice. The two curves show the average shear bond strengths and the average shear strengths of the base concretes at various ages. The data show that good bond strengths have been obtained with LMC overlays in Virginia, and the strengths have been maintained over a 13-yr period. Typically the bond strengths were slightly higher than the strengths of the base concretes.

Figure 8 shows the shear strengths versus age for the bond

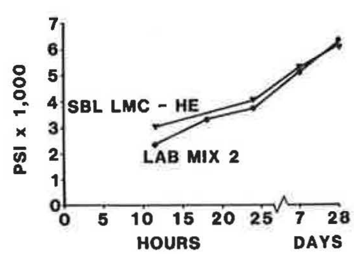

FIGURE 3 Compressive strength vs. age (lab mix 2 and SBL LMC-HE).

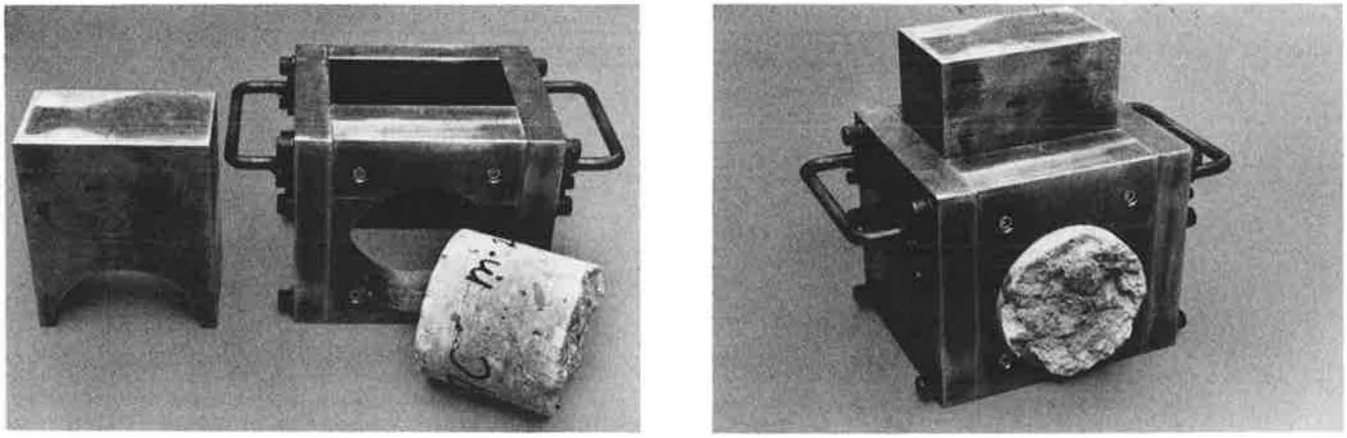

FIGURE 4 Apparatus used to subject cores to shear.

interface and the standard LMC overlay mixture. The LMC has a higher shear strength than the bond interface.

A comparison of the 28-day and 1-yr shear bond strengths for the LMC-HE overlay and the 1–13-year bond strengths for the standard LMC overlays is shown in Figure 9. It is obvious that on the average, the LMC-HE overlay is bonded as well as the standard LMC overlays.

According to Felt, shear bond strengths 200 psi are adequate for good performance (*10*). Based on the data in Table 4 and Figures 5–9, both LMC and LMC-HE have more than adequate bond strength, and LMC-HE can develop adequate bond strength within 12 hours.

A rapid permeability test (AASHTO T 277) was used to measure the permeability to chloride ions of 2-in.-thick slices cut from 4-in.-diameter cores taken from the bridge decks and 4-in. diameter cylinders prepared with the concrete mixtures. The results reported in Table 5 are based on the average of tests on three slices.

Figure 10 shows the relationship between permeability to chloride ion and age for cylinders prepared with a standard

TABLE 4 SHEAR BOND STRENGTHS

	Specimens		Cores	
Age	SBL LMC-HE	NBL LMC-HE	LMC-HE	LMC
6 hr.	---	40	---	---
7 hr.	---	130	---	---
8 hr.	---	150	---	---
9 hr.	---	160	---	---
10 hr.	---	160	---	---
11 hr.	---	290	---	---
12 hr.	360	340	---	---
14 hr.	---	240	---	---
24 hr.	600	400	460	---
7 day	---	650	---	---
28 day	620	550	580	---
1 yr.	---	---	620	740
3 yr.	---	---	---	810
4 yr.	---	---	---	560
8 yr.	---	---	---	780
9 yr.	---	---	---	530
13 yr.	---	---	---	690

NOTE: Units are lb/in.^{2}.

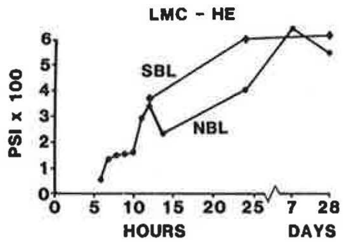

FIGURE 5 Shear bond strength vs. age, LMC-HE (SBL and NBL).

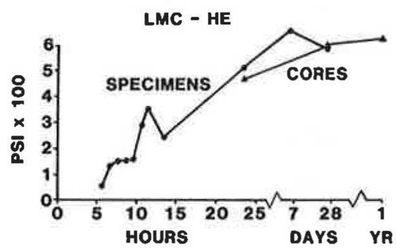

FIGURE 6 Shear bond strength vs. age, LMC-HE (specimens and cores).

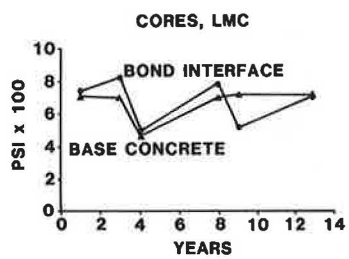

FIGURE 7 Shear strength vs. age, cores, LMC (bond interface and base concrete).

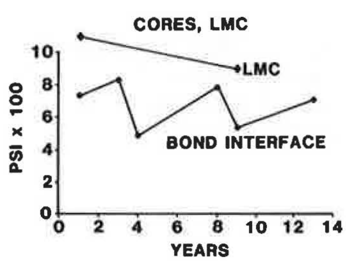

FIGURE 8 Shear strength vs. age, cores, LMC (LMC and bond interface).

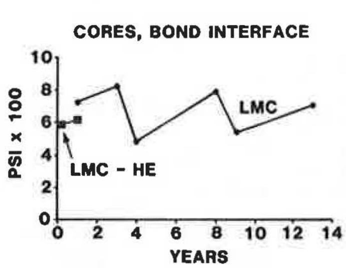

FIGURE 9 Shear strength vs. age, cores, bond interface.

LMC mixture and cores removed from the 12 bridges with standard LMC overlays. It is obvious that the permeability of the standard LMC decreased with age through 4 yr for the cylinders and 9 yr for the cores. The increase reported at 13 yr is likely not typical of LMC but rather an indication of the permeability of an LMC overlay of less than average quality. The reduction in permeability with age agrees with data reported by Whiting (*11*). Based on the test of cores removed from the 12 bridges, the average permeability of a 1.25-in. LMC overlay is 773 coulombs (very low) and that of the A4 concrete below the overlay is 4,590 coulombs (high) (*9*).

A comparison of the relationship between permeability and age for cylinders prepared with the LMC-HE and the standard LMC is shown in Figure 11. The LMC-HE lab mix 2 has a higher permeability at an early age than the standard LMC. However, some standard LMC mixtures have permeabilities of 2,000–3,000 coulombs at an age of 3 weeks. Also, since the permeability of lab mix 2 at an age of 26 weeks was 917 coulombs and at 1 year was 324 coulombs, it is obvious that at later ages, the permeabilities of the LMC-HE is about the same as that of the standard LMC.

A comparison of the permeability of the LMC-HE used on the SBL and lab mix 2 is shown in Figure 12. The cores tested at 4 weeks of age had a permeability of 2,457 coulombs, which falls on the curve for lab mix 2. The cores tested at 1 yr of age had a permeability of 1,464 coulombs. Cylinders tested at 6 and 12 weeks and 1 yr had permeabilities of 1,819, 1,745, and 371 coulombs, respectively. Clearly the LMC-HE used on the SBL has a permeability similar to that of lab mix 2, and it is very low after 1 yr.

A comparison of the permeability of the LMC-HE used on the NBL and lab mix 2 is shown in Figure 13. At an early age both the cores and the cylinders had permeabilities that were higher than for lab mix 2. However, at 1 y-, the average permeability of the NBL cylinders was 347 coulombs, which is about the same as the cylinders for lab mix 2. Also, the permeability of the cores removed after 1 yr in service was 2,018 coulombs, a significant improvement over the 3,269 coulombs obtained at 6 weeks of age. It should be noted that the permeability of the cores is higher than the permeability of the cylinders because the overlay has a minimum thickness of 1.25 in. and therefore as much as 0.75 in. of the 2-in test slice from the cores is A4 concrete rather than LMC-HE. The base concrete exhibited an average permeability of 3,704 coulombs.

Freeze-Thaw Performance

The excellent condition of the 12 bridges with the standard LMC overlays provides evidence that scaling due to freezing and thawing has not been a problem. Nevertheless, six to eight 3-in. × 4-in. × 16-in. beams were prepared during the construction of A4, LMC, and LMC-HE overlays and subjected to the council's freezing and thawing test, a modified version of ASTM C 666 Procedure A, which includes freezing and thawing in a 2-percent NaCl solution (*9*, *12*). The results of the tests are shown in Table 6. Prior to testing, the specimens were moist-cured for 24 hr and air-cured for approximately 6 mo. The standard procedure is to start the test when the specimens are 3 weeks old, but because of problems with

TABLE 5 PERMEABILITY TO CHLORIDE ION

Concrete Age	Type Specimen	Permeability, Coulombs LMC	Lab Mix 2	SBL LMC-HE	NBL LMC-HE
3 wk.	Cylinder	1,462	2,744	---	---
4 wk.	Cores	---	---	2,457	---
6 wk.	Cylinders	---	1,932	1,819	2,783
6 wk.	Cores	---	---	---	3,269
12 wk.	Cylinders	---	---	1,745	3,437
6 mo.	Cylinders	---	917	---	---
6 mo.	Cores	928	---	---	---
1 yr.	Cylinders	---	324	371	347
1 yr.	Cores	712	---	1,464	2,018
3 yr.	Cores	708	---	---	---
4 yr.	Cylinders	80	---	---	---
4 yr.	Cores	545	---	---	---
8 yr.	Cores	367	---	---	---
9 yr.	Cores	464	---	---	---
13 yr.	Cores	1,298	---	---	---

Relationship between Coulombs and Permeability

Coulombs		Permeability
>4000	-	High
2000-4000	-	Moderate
1000-2000	-	Low
100-1000	-	Very Low
<100	-	Negligible

the freeze-thaw machine, the testing of specimens was delayed. All the concrete mixtures passed the test.

Drying Shrinkage

The shrinkage of the LMC-HE at 28 da was 0.042 percent, somewhat greater than the 0.024 percent typical of A4 concrete but slightly less than the 0.049 percent typical for standard LMC concrete (*9*, *12*). The lower shrinkage of the LMC-HE relative to the LMC may be due to the lower water-to-cement ratio of the LMC-HE. Shrinkage values are based on tests of six to eight specimens 3 in. × 3 in. × 11.25 in. subjected to 2 weeks of moist-curing (ASTM C 511) followed by 2 weeks of air-drying in the laboratory.

Skid Resistance

A bald-tire skid number (ASTM E 524) of 41 and a treaded-tire number (ASTM E 501) of 44 were measured at 40 mph several months after the LMC-HE overlay was opened to

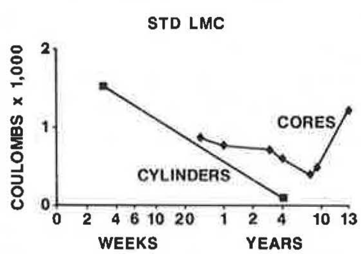

FIGURE 10 Permeability to chloride ions vs. age, STD LMC.

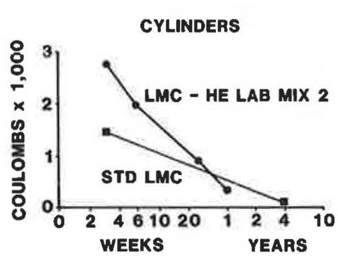

FIGURE 11 Permeability to chloride ions vs. age, cylinders.

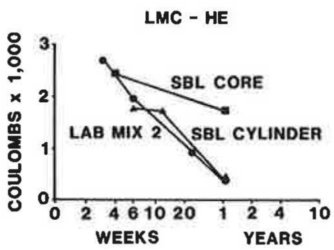

FIGURE 12 Permeability to chloride ions vs. age, LMC-HE (SBL core, lab mix 2, and SBL cylinder).

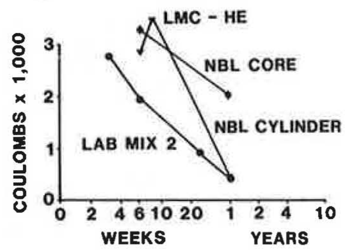

FIGURE 13 Permeability to chloride ions vs. age, LMC-HE (NBL core, lab mix 2, and NBL cylinder).

traffic. Numbers of 46 and 51 respectively, were measured approximately 1 yr later. All four numbers indicate that the tined texture is providing very good skid resistance.

WHY USE AN LMC-HE OVERLAY?

The use of type III cement in pavement and bridge-deck construction has been avoided because of concerns about slump loss, flash set, thermal cracking, sulfate resistance, and durability (*13*). However, these concerns do not apply to a 1.25 in.-thick LMC-HE overlay. The concrete is continuously batched, minimizing the problems associated with slump loss and preventing flash set in the mixer. Also, because the overlay is typically 1.25–2-in. thick, there is insufficient mass to cause major thermal cracks. In addition, the concrete is modified with a polymer and therefore should have sulfate resistance, even though sulfate resistance is not generally needed in a bridge-deck overlay. Finally, concretes prepared with type III cement are durable when used in precast and prestressed concrete members. Freezing and thawing tests conducted in accordance with ASTM C 666 Procedure A indicate that these concretes are durable; therefore, type III cement should be suitable for use in an LMC-HE overlay (*7–9*).

In fact, type III cement may be better suited for use in LMC overlays than are types I and II. In LMC mixtures, the cement gel is gradually formed by cement hydration. As the capillary water is reduced, the polymer particles flocculate to form a continuous close-packed layer on the surfaces of the cement gel and unhydrated cement particles (*14*). Because the hydration process proceeds more rapidly in mixtures with type III cement, the latex film can form more rapidly. Because most LMC overlays are constructed while traffic uses the adjacent lane, a mixture that can be placed and cured in a short time during off-peak traffic periods is less likely to be damaged by traffic and thermal loads than a mixture that cures more slowly.

The results of this study indicate that it is practical to use an LMC-HE overlay to accelerate construction, to reduce inconvenience to motorists, to allow for installation during off-peak traffic periods such as weekends, to provide a more rapid cure in cold weather, to provide low permeability (compared to concrete without latex), and to provide high strength, particularly high early strength.

With the successful installation of the LMC-HE overlay in Virginia, Dow Chemical U.S.A. has continued the use of LMC-HE for overlays where high early strength is necessary. Table 7 shows data reported for the successful installation of an LMC-HE overlay on a one-lane span of the Delaware Memorial Bridge (*15*). The compressive strengths of 4-in. x 8-in. cylinders prepared at the job site are similar to those obtained in Virginia. The permeabilities of slices from cylinders are lower than those obtained in Virginia, and cores removed from the overlay showed that "the bond was excellent" (*15*).

Because it is desirable to use the minimum amount of cement necessary to get the desired strength in the overlay, an effort is under way at Dow Chemical U.S.A. to design LMC-HE mixtures with a lower cement content (*15*). Also modifications to the latex emulsion that would accelerate the hydration of the cement and the formation of the latex film should improve the LMC-HE mixture. Although the concept of an LMC-HE overlay has been implemented, it is likely that with additional trial batching and testing the LMC-HE mixture used in Virginia can be improved.

TABLE 6 FREEZING AND THAWING TEST RESULTS, ASTM C 666-A

Concrete	Weight Loss, %	Durability Factor, %	Surface Rating
A4	1.1	90	1.9
LMC	4.2	92	1.1
LMC-HE	6.9	77	2.2
(Failing values)	>7.0	<60	>3.0

TABLE 7 LMC-HE OVERLAY ON DELAWARE MEMORIAL BRIDGE

Location:	Second Eastbound lane from right curb
Size of Placement:	150 ft by 12 ft-6 in by 1.25 in
Date Installed:	6/18/87
Date Opened to Traffic:	6/19/87
Contractor:	Wagman
Mixture Proportions:	
Cement, Hercules Type III, lb/yd^3	800
W/C	0.36
Sand, York, lb/yd^3	1,416
Stone, lb/yd^3	1,069
Compressive Strength @ 14 days, lb/in^2	5,690
Compressive Strength @ 28 days, lb/in^2	7,490
Permeability @ 14 days, coulombs	1,442
Permeability @ 28 days, coulombs	1,088

SOURCE: L. Kuhlmann and A. Merolla, Dow Chemical U.S.A., personal communications.

CONCLUSIONS

- An evaluation of 12 bridges with LMC overlays ranging in age from 1 to 13 yr indicates that the overlays are soundly bonded to the base concrete and provide good protection against the infiltration of chloride ion.
- The shear strength of the bond between the LMC overlays and the base concretes was about the same or greater than that of the base concrete, indicating that good bonds were achieved and maintained.
- The permeability to chloride ions based on the rapid permeability test was an average of 773 coulombs for a 1.25-in. thick LMC overlay and 4,590 coulombs for the base concretes.
- The bond strengths were about the same for LMC overlays of all ages, but the permeability to chloride ion typically decreased with age.
- Based on the data collected after 1 yr in service, the LMC-HE overlay provides a bond strength and permeability that is equal to that provided by an LMC overlay.
- Based on the early age bond and compressive strength data and 1-year performance data, an LMC-HE overlay can be opened to traffic within 24 hr.

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