TECHNICAL ASSISTANCE REPORT

VERY-EARLY-STRENGTH LATEX-MODIFIED CONCRETE OVERLAY

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

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ABSTRACT

This paper describes the installation and condition of the first two very-early-strength latex modified concrete (LMC-VE) overlays constructed for the Virginia Department of Transportation. The overlays were prepared with a special blended cement rather than the Type I/II cement used in the conventional latex-modified concrete (LMC) overlay. LMC-VE mixture proportions, installation equipment, and procedures are similar to those used for conventional LMC overlays. However, when working with LMC-VE, the contractor must work faster because the concrete loses slump rapidly and the curing period is approximately 3 rather than 72 hours.

Tests of the compressive strength of the LMC-VE overlay performed during the early hours after installation indicated that traffic could be placed on the overlay within 3 hours rather than within the 4 to 7 days required for the conventional LMC overlay. Tests of bond strength and permeability to chloride ion indicated that the overlays are performing satisfactorily and can be used as an alternative to LMC to extend the life of bridge decks.

Pending continuing favorable test results, it is anticipated that LMC-VE overlays can be used when construction during short lane closure periods is highly desirable. Use of LMC-VE may reduce inconvenience to motorists; allow for installation at night; provide negligible to very low permeability; and provide high strength, particularly high early strength.

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INTRODUCTION

Latex-modified concrete (LMC) is a portland cement concrete in which an admixture of styrene butadiene latex particles suspended in water is used to replace a portion of the mixing water. This type of concrete has been used on highway bridges over the past 35 years; it was first used on a bridge deck in Virginia in 1969 *(1,2).*

The Virginia Department of Transportation's (VDOT) specification for LMC overlays requires 13.2 l (3.5 gal) of styrene butadiene latex emulsion (46.5 to 49 percent solids) per bag of cement *(3).* The specification also requires a minimum cement content of 388 kg/m^3 (658 lb/yd^3); a maximum water content of 9.5 l (2.5 gal) per bag of cement; a water-cement ratio (w/c) of 0.35 to 0.40; an air content of 3 to 7 percent; a slump of 100 to 200 mm (4 to 6 in) when measured 4.5 minutes after discharge from the mixer; and a cement, sand, coarse aggregate ratio by weight of 1.0/2.5/2.0.

Compared to concrete without latex, LMC is reported to be more resistant to the intrusion of chloride ions; to have higher tensile, compressive, and flexural strength; and to have greater freeze-thaw resistance *(1)*. The use of LMC overlays, one of the most popular ways to extend the life of bridge decks, inhibits the movement of chlorides to the reinforcement, delaying the onset of corrosion *(4)*. The resistance to chloride intrusion is said to be attributable to the lower w/c and a plastic film produced by the latex particles within the concrete. The higher strength is thought to be attributable to its lower w/c and the stronger bond between the paste and aggregate produced by the plastic film. The greater freeze-thaw resistance is said to be superior because the concrete is less permeable to water and is more flexible, enabling it to withstand better the expansion and contraction associated with frost action *(1)*.

In an increasing number of situations, a bridge in need of an overlay cannot be closed to traffic without significant inconvenience to the public, unless the overlay can be installed during off-peak traffic periods. Because of the slow strength development of conventional LMC mixtures, other systems such as epoxy overlays are often applied to these bridges *(5)*. Epoxy overlays, which can provide 10 to 25 years of protection against chloride intrusion, are thin and tend to follow the contours of the deck. They are not always the best choice for extending the life of a bridge, particularly when an overlay of considerable thickness is needed and when significant patching is required. A high early strength latex-modified concrete (LMC-HE) overlay has been used successfully when a lane can be closed for 1 to 2 days such as over a weekend *(6).* But in many situations, a bridge lane can be closed only for 8 hours or less (such as at night). Therefore, a very-early-strength hydraulic cement concrete overlay system is needed.

PURPOSE AND SCOPE

The purpose of this research was to evaluate an LMC-VE overlay system that could be opened to traffic in approximately 3 hours. The evaluation was based on tests conducted to compare the compressive strength, bond strength, and chloride impermeability of LMC-VE, LMC-HE, and LMC overlays. Data for the LMC-HE and LMC overlays were acquired in a previous study *(6).*

METHOD AND RESULTS

Overlay Descriptions

Two LMC-VE overlays were constructed:

1. One overlay was constructed on Rte. 33 in King and Queen County, Virginia, on the Lord Delaware Bridge over the Mattaponi River (Structure No. 1949). The bridge was constructed in 1945 and has 33 simple spans; concrete beams; and two lanes, one eastbound (EBL) and one westbound (WBL). The average daily traffic was 14,000 in 1997.

2. The other overlay was constructed on Rte. 620 (Braddock Road) on the WBL of a structure over I-495 in Fairfax County, Virginia. The structure is a four-span, continuous steel beam structure with three lanes. The average daily traffic was 63,632 in 1997.

Installation of LMC-VE Overlays

The procedures for installing the LMC-VE overlays were the same as for installing an LMC overlay, although the time required for each step was less. The deck was scarified to remove the top 13 mm (0.5 in) of the old concrete. Both structures had a polyester styrene overlay 13 mm (0.5 in) thick that was failing, which was also removed. No patching was done. Within 2 hours prior to the placement of the overlay, the exposed surfaces of the concrete were shotblasted, sprayed with water, and covered with a sheet of polyethylene. Figure 1 shows the LMC-VE concrete overlay being placed and consolidated on the middle lane of the bridge on Rte. 620. The contractor is humidifying the air behind the screen using a fog spray to prevent plastic shrinkage cracks. The overlay was quickly covered with wet burlap and polyethylene to provide a moist environment during the 3-hour curing period (Figure 2). The overlay was required to be at least 32 mm (1.25 in) thick, but the average thickness of the Rte. 620 overlay was 64 mm (2.5 in).

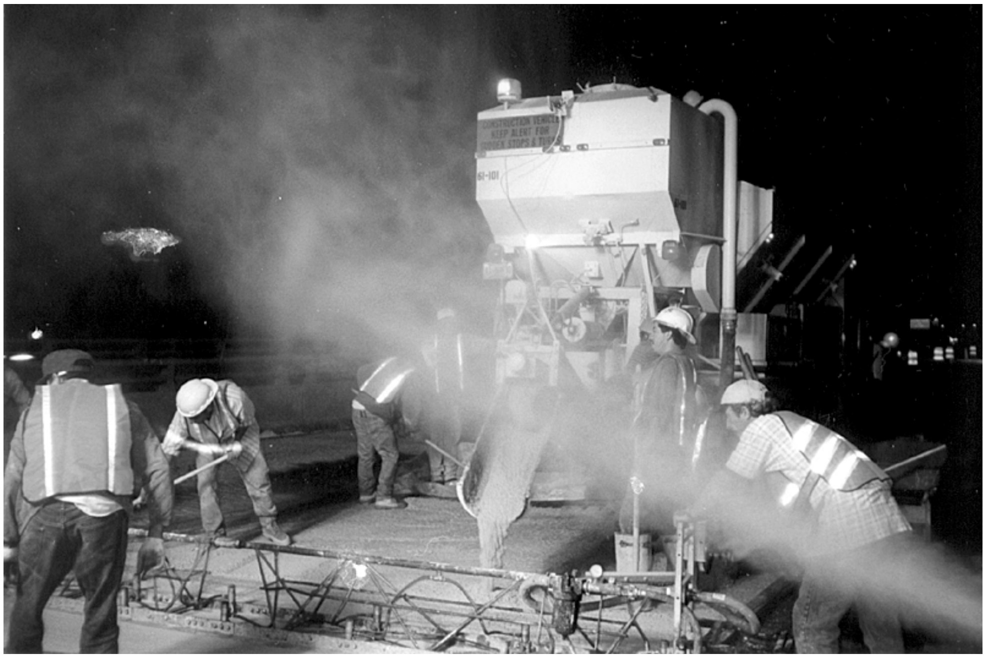

FIGURE 1. LMC-VE overlay is placed and consolidated on middle lane of bridge on Rte. 620. A fog spray humidifies the air behind the screed to prevent plastic shrinkage cracking.

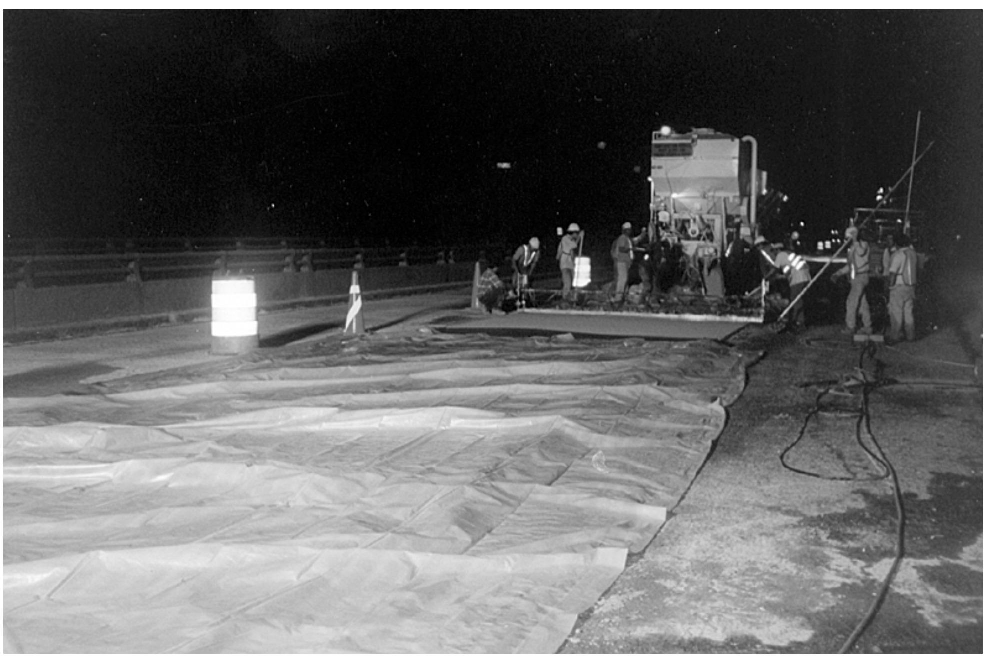

FIGURE 2. LMC-VE overlay is quickly covered with wet burlap and polyethylene to provide a moist cure. The overlay can receive traffic in as little as 3 hours.

Typical procedures called for a lane to be closed at 9 P.M., the surface shotblasted until 11 P.M., concrete placed from 11 P.M. to 2 A.M., and the lane reopened to traffic at 5 A.M. Table 1 gives the exact times and dates, along with information from measurements of the plastic concretes. Table 2 gives the physical and chemical properties of the cement used in

TABLE 1. LMC-VE Installation Data

Date	Time	Lane	Load No.	Air, %	Slump, mm	in	Air temperature, °C (°F)	Mix temperature, °C (°F)	Evaporation rate, kg/m^2/h (lb/ft^2/h)	Cylinder cast	Cure time, h
9/3/97	12:30 AM	E1-E4, 33	1	-[a]	-	-	24 (76)	26 (78)	0.5 (0.1)	-	5.5
9/9/97	1:00 AM	E5-E8, 33	1	-	-	-	23 (74)	24 (76)	0.25 (0.05)	-	5.0
9/11/97	1:00 AM	E9-E12, 33	1	-	-	-	21 (70)	23 (74)	0.5 (0.1)	-	5.0
9/15/97	12:30 AM	E13-16, 33	1	-	-	-	23 (73)	24 (76)	0.5 (0.1)	-	5.5
9/16/97	1:15 AM	E17-20, 33	1	-	-	-	19 (66)	21 (70)	0.4 (0.08)	-	4.75
9/17/97	2:15 AM	E21-24, 33	1	-	-	-	20 (68)	22 (72)	0.5 (0.1)	-	5.75
9/18/97	1:00 AM	E 25-28, 33	1	-	-	-	21 (70)	24 (76)	0.4 (0.08)	-	5.0
9/22/97	1:30 AM	E29-33, 33	1	-	-	-	17 (62)	21 (70)	0.5 (0.1)	-	4.5
9/23/97	1:00 AM	W1-4, 33	1	-	-	-	18 (64)	20 (68)	0.5 (0.1)	-	5.0
9/24/97	12:30 AM	W5-9, 33	1	-	-	-	21 (70)	23 (74)	0.25 (0.05)	-	5.5
9/30/97	1:30 AM	W10-14, 33	1	-	-	-	20 (68)	22 (72)	0.5 (0.1)	-	4.5
10/1/97	1:30 AM	W15-19, 33	1	-	-	-	16 (60)	21 (70)	0.5 (0.1)	-	4.5
10/2/97	12:30 AM	W20-24, 33	1	-	-	-	18 (64)	22 (72)	0.5 (0.1)	-	5.5
10/6/97	1:00 AM	W25-28, 33	1	-	-	-	24 (76)	27 (80)	0.25 (0.05)	-	5.0
10/7/97	12:30 AM	W29-33, 33	1	-	-	-	22 (72)	26 (78)	0.5 (0.1)	-	5.5
5/27/98	11:00 PM	IS,620	1	5.4	70/159	2.75/6.25	17 (62)	17 (63)	0.05 (0.01)		8.5
5/28/98	12:10 AM	IS,620	2	4.9	171	6.75	16 (60)	20 (68)	-	12:40 AM	7.5
5/28/98	1:13 AM	IS,620	3	5.4	137	5.5	16 (60)	21 (69)	-		6.5
5/28/98	12:00 AM	M,620	1	5.2	159	6.25	20 (68)	21 (70)	-		4.0
5/29/98	1:30 AM	M,620	2	6.3	160	4	20 (68)	24 (76)	0.10 (0.02)	1:45 AM	3.0
5/29/98	2:35 AM	M,620	3	6.2	157	6	17 (63)	23 (73)	0.10 (0.02)		2.5
5/29/98	10:48 PM	0S,620	1	7	178	4.5	24 (76)	24 (76)	0.10 (0.02)	11:15 PM	9.0
5/29/98	11:38 PM	0S,620	2	6.4	163	5.25	24 (75)	24 (76)	0.10 (0.02)	12:10 AM	8.0
5/30/98	12:50 AM	0S,620	3	6.4	163	5	24 (76)	26 (78)	-		7.0
6/1/98	9:30 PM	0S,620	1	7.8	198	8	22 (71)	27 (80)	-	9:40 PM	7.5

[a]No data recorded.

TABLE 2. Physical and Chemical Properties of Cements

	Type overlay LMC-VE	LMC-VE	LMC-HE	LMC
	Type cement SB1	SB2	MT-III	MT-II
Chemical analysis (%)				
SiO_2	15.50	14.55	20.82	21.3
Al_2O_3	12.45	13.15	4.44	4.4
Fe_2O_3	1.41	1.25	2.12	4.3
CaO	51.19	42.33	62.23	63.7
MgO	0.99	2.14	3.24	3.0
SO_3	14.16	14.96	4.40	2.7
Ignition loss	1.65	1.99	0.90	0.5
Physical analysis				
Blaine fineness (m^2/kg)	642	775	504	365
Compressive strength, MPa (psi) (cubes)				
3 h	25.6 (3720)	14.7 (2130)	-	-
6 h	30.3 (4400)	25.0 (3630)	-	-
1 d	32.9 (4780)	33.1 (4810)	20.7 (3010)	-
3 d	-	-	33.5 (4860)	22.5 (3270)
7 d	44.4 (6440)	44.6 (6470)	40.9 (5930)	27.8 (4040)

TABLE 3. Mixture Proportions, kg/m^3 (lb/yd^3)

Mixture	LMC-VE	LMC-HE	LMC
Cement	388 (658)	481 (815)	388 (658)
Fine aggregate	944 (1600)	827 (1402)	927 (571)
Coarse aggregate	689 (1168)	674 (1142)	728 (1234)
Latex (includes 52% water)	121 (205)	129 (218)	121 (205)
Water	81 (137)	97 (164)	81 (137)

the two batches on Rte. 620, along with data for a Type III and Type II cement used with LMC-HE and LMC overlays included for comparison. Table 3 gives the mixture proportions used on Rte. 620, along with proportions for LMC-HE and LMC overlays included for comparison.

Very early strength is achieved with the special blended cement because of the fineness and the high Al_2O_3 and SO_3 content. High early strength is achieved with the LMC-HE because of the Type III cement and the higher cement content.

Compressive Strength

Cylinders of concrete, 100 mm in diameter and 200 mm high (4 in diameter, 8 in high), were fabricated and tested in compression using steel end caps and neoprene pads (AASHTO T-22). During the first 24 hours of age, the specimens were cured in plastic molds with wet burlap on the surface. Specimens to be tested at 1 day and later were removed from the molds at 24 hours of age and air cured in the laboratory. The results shown in Table 4 are based on tests on three cylinders unless otherwise indicated.

TABLE 4. Compressive Strength, MPa (psi) (cylinders)

Batch	2 h	3 h	3.5 h	4 h	4.5 h	5 h	6 h	7 h	24 h	7 d	28 d
33 E1	-[a]	20.5 (2980)	-	-	-	-	-	-	-	-	-
33 E5	-	-	-	-	-	25.8 (3750)	-	-	-	-	-
33 E9	-	-	29.3 (4250)	-	-	-	-	-	-	-	-
33 E13	-	-	-	18.6 (2700)	-	-	-	-	-	34.7 (5040)	-
33 E17	-	-	-	29.6 (4300)	-	-	-	-	-	-	-
33 E21	-	-	-	32.4 (4700)	-	-	-	-	-	-	-
33 E25	-	-	-	30.0 (4350)	-	-	-	-	-	-	-
33 E29	-	-	-	-	31.7 (4600)	-	-	-	-	-	-
33 W1	-	-	-	-	30.7 (4450)	-	-	-	-	43.6 (6330)	-
33 W5	-	-	-	31.0 (4500)	-	-	-	-	-	-	-
33 W10	-	-	-	31.3 (4550)	-	-	-	-	-	36.2 (5250)	-
33 W15	-	-	-	-	-	28.6 (4150)	-	-	-	-	-
33 W20	-	-	-	25.8 (3750)	-	-	-	-	-	-	-
33 W25	-	-	-	29.6 (4300)	-	-	-	-	-	-	-
33 W29	-	-	-	-	-	31.3 (4550)	-	-	-	36.0 (5220)	-
620-1	-	22.5 (3260)[b]	-	28.5 (4140)[b]	-	33.2 (4820)[c]	-	-	-	38.2 (5550)	-
620-2	15.4 (2230)[b]	17.8 (2590)[b]	-	17.3 (2510)[b]	-	-	-	-	-	36.6 (5310)	-
620-3	-	11.5 (1670)[b]	-	12.3 (1790)[b]	-	14.8 (2150)[b]	-	-	-	36.4 (5290)	-
620-4	1.9 (280)[b]	-	-	-	-	4.5 (660)[c]	-	6.1 (880)[b]	-	-	-
LMC-HE	-	-	-	-	-	-	-	2.2 (320)[c]	24.8 (3600)	34.0 (4940)	39.3 (5700)
LMC	-	-	-	-	-	-	-	0.8 (120)[c]	10.8 (1570)	23.2 (3360)	31.9 (4630)

[a]No data recorded.
[b]One cylinder.
[c]Average of two cylinders.

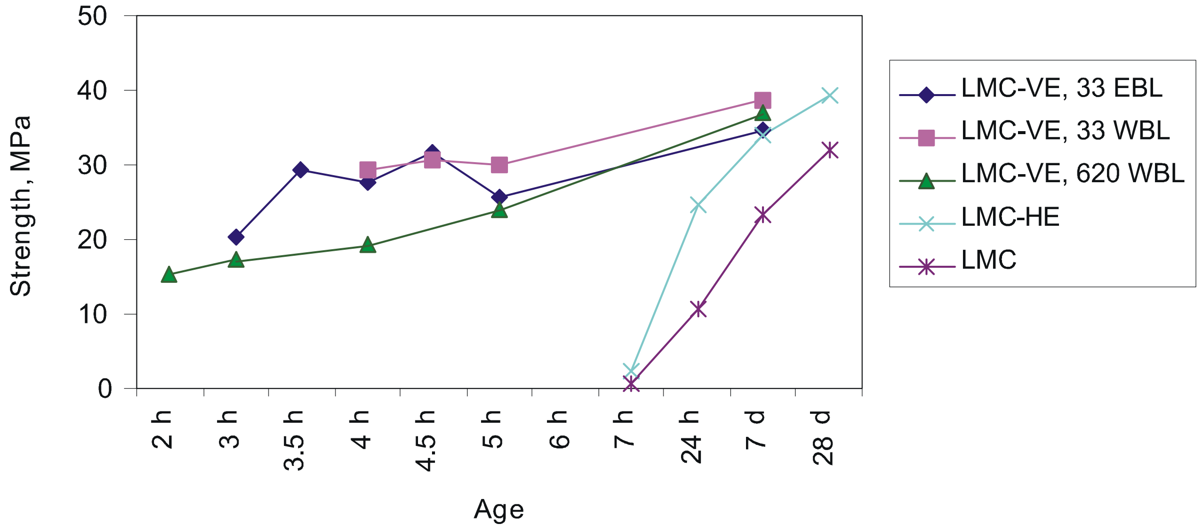

FIGURE 3. Strength vs. age for LMC-VE, LMC-HE, and LMC

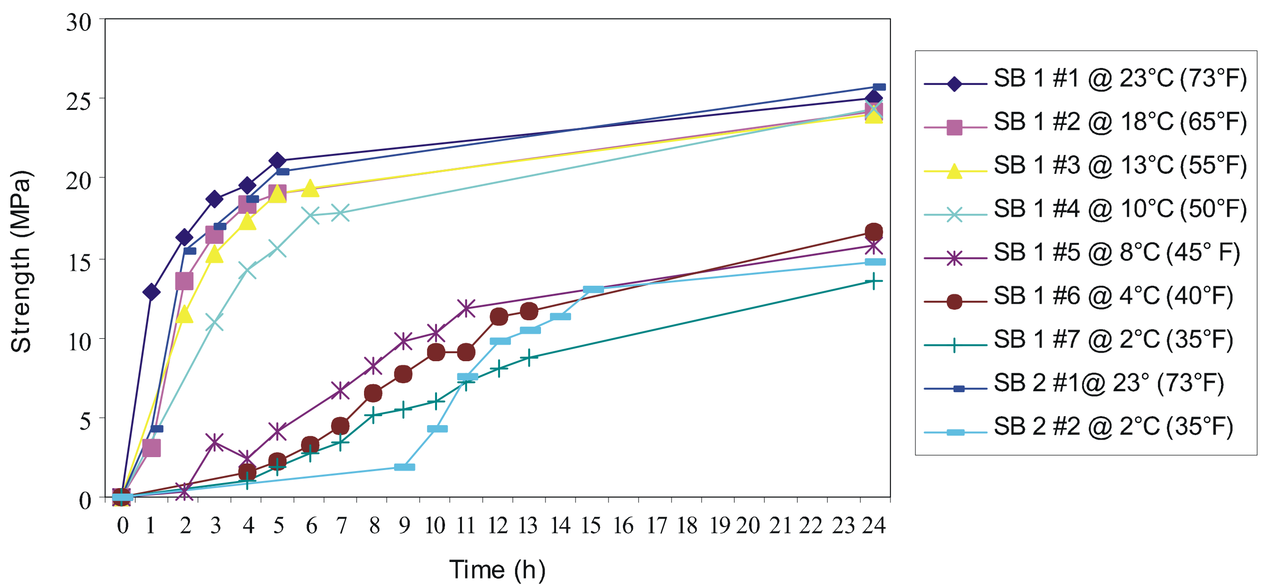

FIGURE 4. Strength vs. age for LMC-VE cured at selected temperatures

Curing temperature is also a major factor in the development of compressive strength. Figure 4 shows the strength vs. age relationship for two batches of special blended cement cured in the laboratory at selected temperatures. The SB2 sample was slower to develop early strength at both 23° C (73° F) and 2° C (35° F), but strength at 24 hours was about the same for the two cements. Curing temperatures below 10°C (50° F) significantly retarded early strength development, and it was concluded that an overlay placed at these temperatures should not be subjected to traffic until adequate strength is obtained. Also, VDOT's specification does not allow the placement of LMC at temperatures below 10° C (50° F) *(3)*.

Permeability to Chloride Ion

LMC overlays usually extend the life of a bridge deck by reducing the infiltration of chloride ions. The rapid chloride ion permeability test (AASHTO T277) provides a good indication of the level of protection. Table 5 provides the results of tests on cylinders prepared at the job sites, cured in cylinder molds for 24 hours, and cured in air thereafter until tested. The values for tests at 4 weeks of age are similar to those found for conventional LMC. The values for tests at 6 weeks, 5 months, and 12 months of age are lower than the 1000, 800, and 500 coulomb values, respectively, typically obtained for conventional LMC (Figure 5).

TABLE 5. Permeability to Chloride Ion, coulombs

	Sample No.				
Bridge	1	2	3	4	5
Rte. 33 (avg. of 2 specimens tested at 5 mo)	14	3	4	8	8
Rte. 33 (avg. of 2 specimens tested at 12 mo)	1	0	3	2	0
Rte. 620 (avg. of 2 specimens tested at 4 wk)	1346	1683	1158	-[a]	-
Rte. 620 (1 specimen tested at 6 wk)	678	867	372	-	-

[a]No data recorded.

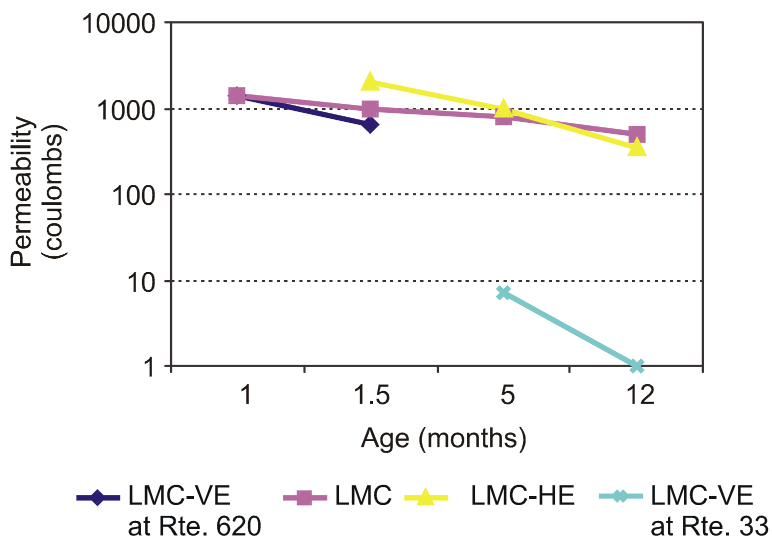

FIGURE 5. Permeability vs. age for LMC-VE, LMC-HE, and LMC

Bond Strength

A major factor controlling the life of an overlay is the strength of its bond with the old deck concrete. Table 6 shows the results of tensile adhesion tests conducted on cores removed from the overlays. Failures in the base concrete just below the bond interface typically indicate damage caused by concrete removal operations such as the use of milling machines. When failure occurred in the base concrete, the bond strength was not measured but was considered to be at least as high as the tensile strength of the base concrete. Ninety percent of the failure area

TABLE 6. Tensile Adhesion Bond Strength

Bridge	Strength, MPa (psi)	Failure mode, %		
		Base	Bond	Overlay
Rte. 33	1.05 (153)	90	7	3
Rte. 620	1.15 (167)	82	17	1

for cores tested from Rte. 33 was in the base concrete. Three cores failed just below the bond line, and three at deeper levels. The 1.05 MPa (153 psi) value was indicative of the strength of the old concrete. Likewise, 82 percent of the failure area for four cores tested from Rte. 620 were in the base concrete just below the bond line. The 1.15 MPa (167 psi) value was indicative of the strength of the damaged surface. Fortunately, one core from Rte. 33 and one from Rte. 620 had tensile strengths of 1.71 MPa (248 psi) and 1.90 MPa (276 psi), respectively. These values illustrate the potential of LMC-VE to provide high bond strength.

Cracking

High performance concrete overlays are susceptible to plastic shrinkage cracking. Plastic shrinkage cracking occurred in both bridge overlays. For the Rte. 620 overlay, minor cracking was noted on the inside lane, less on the middle lane, and a considerable amount on the outside lane. Some cracks were the width of a knife blade, and others were tight. The cracks were typically 2.5 mm (1 in) or less in depth; the uncracked lower portion of the concrete overlay (at least 32 mm [1.25 in] deep) can provide adequate protection. Transverse cracks were noted in all three lanes. These cracks occurred primarily over the negative moment areas and were likely caused by reflective cracking from the base concrete because of traffic loads. The transverse cracks were tight. Wider cracks were sealed with a gravity fill crack sealer prior to saw cutting of the grooves in the surface for skid resistance. Plastic shrinkage cracking also occurred in about half of the spans on the Rte. 33 overlay. The cracks were typically near the outside edge of the WBL where the screed rollers reversed direction when striking off the overlay.

Cost

Table 7 provides cost data for four overlay systems. The special blended cement required for the LMC-VE costs 400 percent more and the Type III cement used in the LMC-HE costs 20 percent more than Type I/II cements used in the conventional LMC overlays. These cements increase the cubic meter cost of the concrete by approximately $120 and $9 (cubic yard, $90 and $7), respectively. These costs are more than offset by the large savings in the cost of traffic control. The cost for traffic control for LMC-VE overlays is the same as that for epoxy overlays. Departments of transportation that spend $5 million per year on deck rehabilitation can save up to $1.25 million per year by using LMC-VE overlays. LMC-VE and LMC-HE overlays can be done for approximately 25 percent less than conventional LMC overlays.

TABLE 7. Cost of Bridge Deck Protective Treatments, $/m^2 ($/yd^2)

	LMC[a]	Epoxy[b]	LMC-VE[c]	LMC-HE[c]
Treatment	73 (61)	29 (24)	78 (65)	73 (61)
Miscellaneous	28 (23)	0 (0)	28 (23)	28 (23)
Traffic	55 (46)	9 (8)	9 (8)	9 (8)
Total	156 (130)	38 (32)	115 (96)	110 (92)
Life (years)	30	15	30	30
Life cycle	156 (130)	56 (47)	115 (96)	110 (92)
% control	100	36	74	71

[a]Data from 52 installations in Virginia, 1994 and 1995.
[b]Data from 27 installations in Virginia, 1994 and 1995.
[c]Data from most appropriate cost element from *a* and *b,* with treatment cost adjusted for extra cost of cement.

CONCLUSION

LMC-VE overlay installations on Rte. 33 and Rte. 620 in Virginia demonstrate that these overlays can be placed and opened to traffic with as little as 3 hours cure time and that the initial condition of the overlays is as good as that of the more proven LMC-HE and conventional LMC overlays. LMC-VE overlays are an economical alternative to conventional concrete overlays.

RECOMMENDATION

LMC-VE overlays should be used to reduce the cost of overlay construction and to minimize the inconvenience to motorists of overlay construction.

ACKNOWLEDGMENTS

DOW Chemical U.S.A. and CTS Cement initially developed the LMC-VE concrete mixture and worked with contractors and departments of transportation to implement the mixture first for patching and eventually for overlays. Fred Sutherland, Lou Kuhlman, and Al Merolla of Dow and Ed Rice of CTS brought the technology to VDOT. Lanford Brothers Construction Co. Inc. and Tessa Martin Co. Inc. encouraged VDOT to use the LMC-VE mixtures on Rte. 33 and Rte. 620, respectively. Mike Shelton and Nick Nicholson, District Structure and Bridge Engineers in Fredericksburg and Northern Virginia, respectively, agreed to try the new overlay system.

Installation data were provided by Bryan Boyle, Inspector, and Bobby Broyles, Materials Technician, for the Rte. 33 and Rte. 620 jobs, respectively. Test cores were provided by Mike Shelton and Claude Riffe, Materials Engineer, for the Rte. 33 job and Bobby Broyles for the Rte. 620 job. Test cylinders were provided by Bob Milliron of Lanford Brothers Co. Inc., for the Rte.

33 job and Bobby Broyles for the Rte. 620 job. Permeability tests were done by Mike Burton and Larry Lundy. Cement tests were done by Larry Lundy. Linda Evans edited the report.

The installations were successful because of the industry-government partnership and the individual efforts of those acknowledged. Use of very-early-strength overlay systems is being encouraged by the AASHTO Lead State Team for Concrete Assessment and Rehabilitation, and these installations show that VDOT is a leader in the implementation of these SHRP products.

REFERENCES

1. Dow Chemical U.S.A. *Lower Lifetime Costs for Parking Structures with Latex Concrete Modifier*. Form No. 173-1089-80. Midland, Mich., 1980.

1. Hilton, M. H., H. N. Walker, and W. T. McKeel, Jr. *Latex Modified Portland Cement Overlays: An Analysis of Samples Removed from Bridge Decks.* VHTRC 76-R25. Virginia Highway and Transportation Research Council, Charlottesville, 1976.

2. Virginia Department of Transportation. *Metric Road and Bridge Specifications.* Richmond, January 1997.

3. Sprinkel, M.M. Twenty Year Performance of Latex Modified Concrete Overlays. In *Transportation Research Record 1335*, TRB, National Research Council, Washington, D.C., 1980, pp. 27-35.

4. American Association of State Highway and Transportation Officials. *Guide Specifications for Polymer Concrete Bridge Deck Overlays.* AASHTO-AGC-ARTBA Task Force 34. Washington, D.C., March 1995.

5. Sprinkel, M.M. High Early Strength Latex Modified Concrete Overlay. In *Transportation Research Record 1204*, TRB, National Research Council, Washington, D.C., 1988, pp. 42-51.