Using Styrene-Butadiene Latex in Concrete Overlays

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This paper will review the material and end-use properties of concrete containing styrene/butadiene latex. Information on mix design is included, with special emphasis on construction techniques. Field performance data are cited, particularly on resistance to chloride penetration. Reports from several states that have many years of experience with LMC are referenced for their performance history.

Thirty years ago, the world's first latex-modified portland cement bridge-deck overlay was installed on a small bridge in northern Michigan by a crew using simple hand tools and directed by research personnel. An experimental system then, concrete modified with styrene-butadiene latex has now grown to be accepted as a standard material of construction covering millions of square yards of bridge and parking decks, installed at an estimated rate of 80,000 yd^3/yr. Latex for this use is supplied by three manufacturers: Dow Chemical Co., Polysar Inc., and Reichhold Chemical Company (*1*). Latex-modified concrete (LMC) has proven to be a reliable method for not only the repair of existing deteriorated bridges and parking structures, but also for protection of new concrete decks.

MIX DESIGN

The inclusion of latex in concrete reduces water demand of the mix, achieving a workable slump (4–6 in.) at a water-cement ratio of 0.40 or less. This includes the water in the latex, typically 52 percent by weight.

The primary criteria for LMC overlays are workability in the plastic state, bond and low permeability in the hardened state. The higher sand content typical in workable LMC mixes is not a concern because compressive strength is not a significant design factor.

Although the sand-stone ratio will vary with the particular aggregate used, a typical mix design for LMC would be:

Component	*Amount*
Cement, type I	658 lb
Sand	1,710 lb
Stone	1,140 lb
Latex	24.5 gal
Water	19 gal, maximum

In LMC, unlike conventional concrete, air entrainment is not required for freeze-thaw durability. The latex itself apparently provides this protection. However, some air is entrained by the latex during the mixing process so it is common for a specification to include a maximum air content, typically 6.5 percent, but not a minimum.

Normally, type I or type I/II cement is used in LMC. For special needs, however, type III cement has been successfully utilized. On the Marquam Street Bridge in Portland, Oregon, it was used to decrease setting time to minimize movement on the superelevations (*2*). In Virginia (*3*) and Delaware, type III cement was incorporated in the LMC mix to shorten curing time and to allow traffic on the overlay in 24 hr.

Dow Chemical Co., Midland, Mich. 48640.

PROPERTIES

The properties of concrete containing latex are changed in several ways. In the plastic state, the latex functions as a water reducer, providing a workable mixture at low water-cement ratios. However, at high temperatures, rapid slump loss will occur along with increased placing difficulties. In the hardened state, this low water-cement ratio, combined with the film characteristics of the latex, improves bond, freeze-thaw resistance, flexural strength, and permeability (*1*). The effect of the cured latex on the concrete can be seen with a microscope. In Figure 1, cured LMC and conventional concrete are compared at 12,000 magnification. The microvoids of the unmodified concrete are filled by the latex film in the LMC. This is also evident in Figure 2 where photos (*4*) of latex-modified and conventional mortars, as seen through the fluorescent microscope, are compared. Here the micropores in the unmodified are filled with the fluorescent agent, indicating penetration of the agent, whereas the latex modified shows very little penetration.

Figures 3–7 contain some of the typical properties of LMC. It should be noted that most of these data are ranges of values, typical of those reported by various state highway departments and in published research reports. Little has been reported on the effect of latex on modulus of elasticity, but current data indicate that LMC will yield a modulus that is approximately 85 percent of conventional concrete made of the same materials. All of these results are based on a cure cycle of 1 day at 100 percent relative humidity (RH) and subsequent time in dry air, typically 50 percent RH.

Several years ago, an electrical test was developed to determine the chloride permeability of hardened concrete (*5*). This Rapid Permeability Test (AASHTO T 277) requires only 2 days to complete, rather than the 90 days for the AASHTO ponding test, T 259-78 (*6*). Table 1 lists the ranking of the concretes in terms of their permeability as determined by this Rapid Permeability Test. Research studies (*7–9*) using this test procedure have also shown the improved permeability

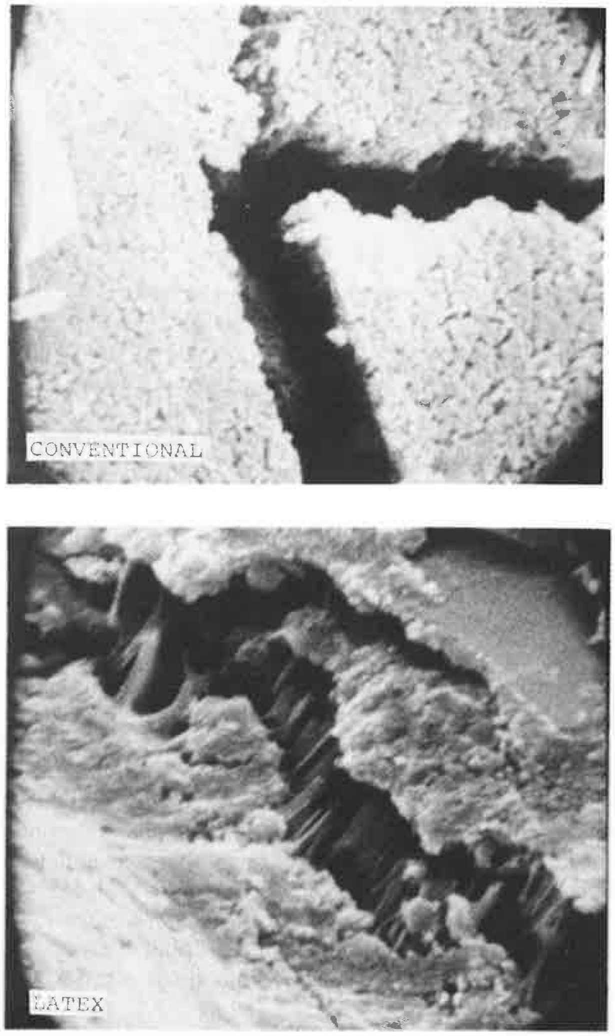


FIGURE 1 Microscopic photographs of latex-modified and conventional concretes (magnification = 8,880×).

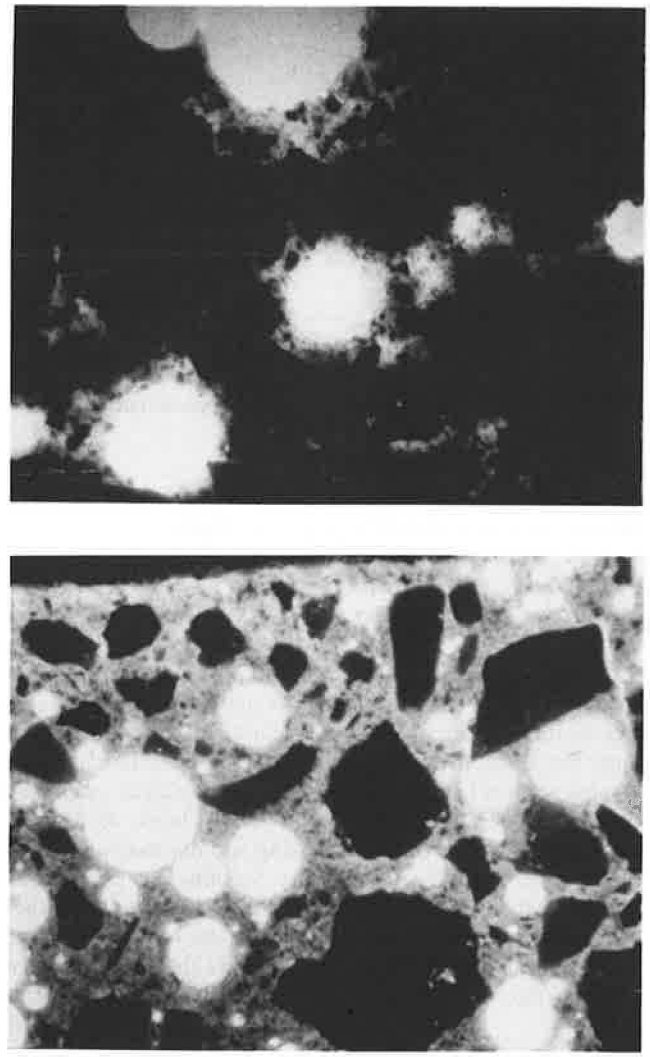


FIGURE 2 Photos of latex-modified and conventional mortars through the fluorescent microscope.

performance of LMC and the effect of variables such as air content and cure time.

APPLICATION TECHNIQUES

Surface Preparation

A clean, sound surface is the key to any material being prepared for adhesion. First, all unsound concrete must be removed from the surface whether the deck is new concrete receiving a protective overlay or deteriorated concrete being repaired. Scarifiers, shotblasters, or scabblers are typically used for this process. Hydrodemolition is a recent development that holds promise for efficient concrete removal with little or no damage to the remaining concrete. Hand clipping follows if there are deep pockets of deteriorated concrete or if concrete below reinforcing steel needs to be removed. The entire area is then blasted to clean surface laitance from the concrete and rust from the rebar. Sandblasting has been the most common and efficient method, although waterblasting has merit in areas

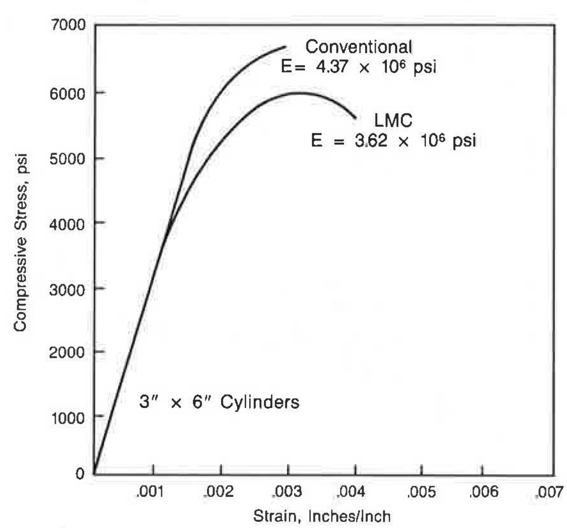


FIGURE 3 Modulus of elasticity of styrene-butadiene latex-modified concrete.

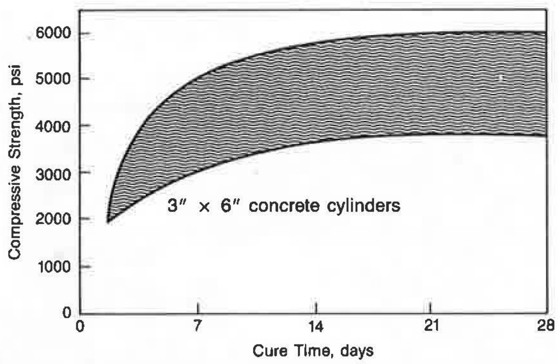
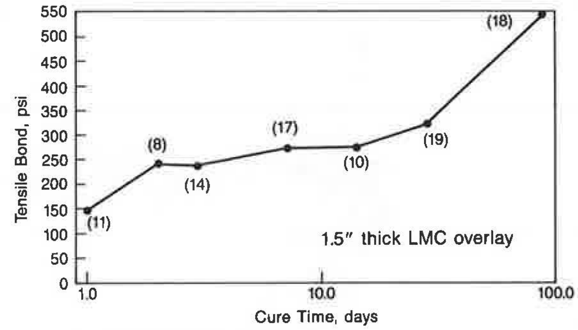


FIGURE 4 Compressive strength of styrene-butadiene latex-modified concrete.



1. Tensile stength of bases >600 psi
2. % coefficient of variation in ( )
3. Failures were predominantly cohesive

FIGURE 6 Tensile bond strength of styrene-butadiene latex-modified concrete.

concerned with dust. In either case, the dust and debris must be removed, so that a clean surface is provided.

Mixing

Accurate proportioning and thorough mixing are key requirements for LMC. For LMC and particularly for projects where significant quantities of quality concrete are distributed over large flat areas, the self-contained, mobile, continuous mixer is most appropriate. These machines (Figure 8) carry enough unmixed materials (sand, stone, cement, latex, and water) for at least 6 yd^3 of concrete, mixing and discharging only as much concrete as needed by the finishing operation. The machines should be calibrated regularly to assure the owner of an accurate mix design. In addition, they minimize waste and clean-up time because the auger is the only part that contains mixed concrete.

Placement

The normal construction practice is to drive the mixer to the area of placement and to discharge directly onto the work area. However, where load or space restrictions limit the access of the mixer, alternate means have been used. These include buggies, buckets, and pumps (Figure 9).

If the project contains deep repair areas, these can be handled in one of two ways: (a) LMC can be placed into the deep repair areas simultaneous with the overlay or (b) conventional concrete can be placed first to fill deep holes; the areas are then brought to grade, cured, and overlaid with LMC. If the latter is selected, the conventional concrete should be sandblasted prior to placement of the LMC.

In either case, the placement of LMC is preceded by wetting the substrate concrete, normally within 24 hr. It is desirable to cool the deck in hot weather. Standing water and puddles are removed by oil-free compressed air.

To ensure bond, the LMC is normally broomed into the surface of the deck to enhance contact between the mortar phase and the substrate. (In this process, overlooked dirt and debris may be included in the mix, rather than remain a bond-breaker under it.) Any excess stones that accumulate are discarded.

An alternative to the above is the use of a latex mortar grout prepared in a separate mixer and applied just ahead of the concrete overlay. This method has also worked well.

Finishing

Self-propelled roller finishers (Figure 10) have proven to be the most popular method of screeding and finishing LMC. The auger, rollers, and vibrating pan combine to provide the proper thickness of overlay. Prior to the placement, the finisher is "calibrated" with shims to assure the contractor and

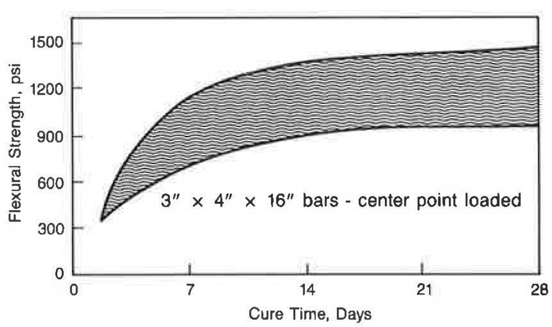


FIGURE 5 Flexural strength of styrene-butadiene latex-modified concrete.

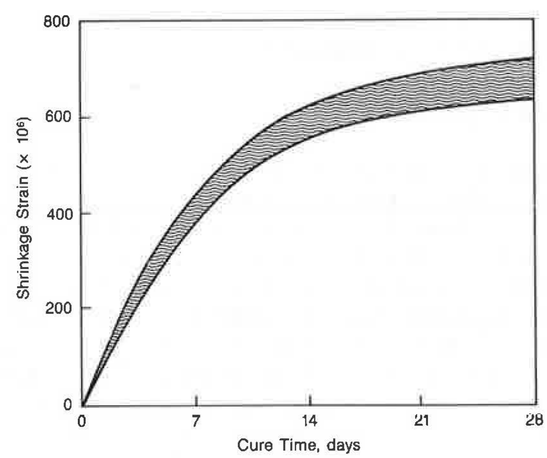


FIGURE 7 Shrinkage of styrene-butadiene latex-modified concrete.

TABLE 1 INTERPRETATION OF RESULTS OF RAPID CHLORIDE PERMEABILITY TEST

Chloride permeability	Charge passed, coulombs	Type of Concrete
High	4000	High water-cement ratios 0.6
Moderate	2000-4000	Moderate water-cement ratios (0.4 to 0.5)
Low	1000-2000	Low water-cement ratios, Iowa dense concrete
Very low	100-1000	Latex modified concrete

FIGURE 8 Continuous mixer.

owner that the proper thickness will be applied to the deck. In locations where a drag or broom finish is desired, this is accomplished by an attachment on the machine. If a grooved finish is required, a workman with a rake is positioned on a workbridge directly behind the finishing machine. In either case, the finishing operation should be completed before the surface of the LMC overlay begins to dry.

FIGURE 9 Placement by pump.

Curing

As soon as the finishing operation is complete, wet burlap is applied, followed by white or clear polyethylene film. The intent is to keep the surface damp for approximately 24 hr. The burlap is not to be dripping wet, and the polyethylene film should be held down at the edges with lumber or suitable weights to prevent it from being blown off. After this initial damp cure, the film and burlap are removed to allow air-drying. It is during the air-cure period that LMC gains its physical properties.

WEATHER LIMITATIONS

Latex-modified concrete sets and gains strength at about the same rate as conventional concrete. Indiana studied the setting time of LMC (*10*) and compared it to a conventional concrete, using ASTM C 403, Time of Setting of Concrete Mixtures by Penetration Resistance. The results, shown in Figure 11, demonstrate that LMC does not set any faster than concrete without latex. It will, however, form a "crust" or relatively dry layer on the surface if exposed to dry air for prolonged periods, even though the concrete underneath is

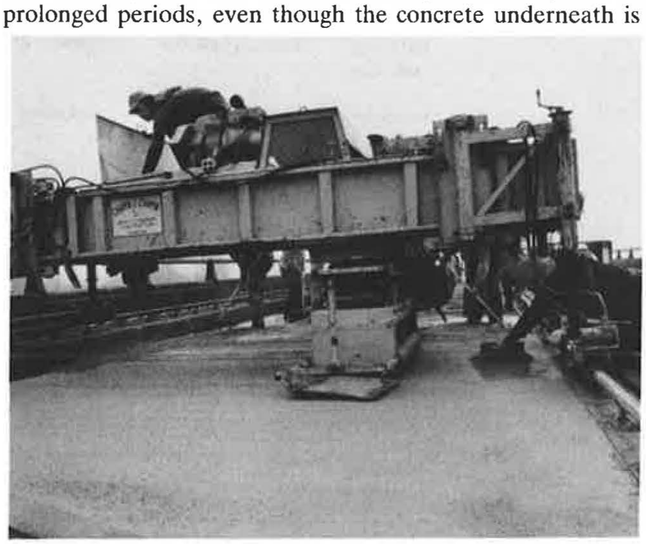


FIGURE 10 Double-roller finisher.

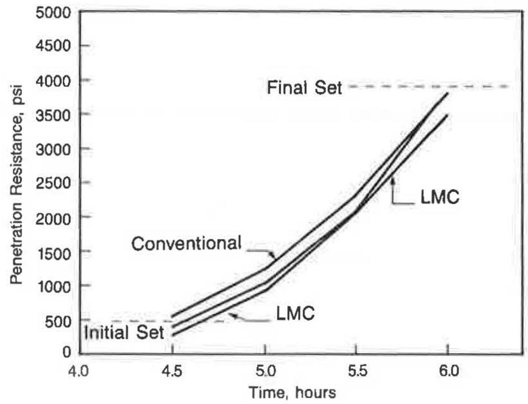


FIGURE 11 Time of set (ASTM C-403) of LMC and conventional concrete.

still quite plastic. This is caused by drying of the latex itself and, if not controlled, can result in tearing during the finishing operation. This condition is aggravated by hot, dry, windy conditions and can be minimized by following ACI's Recommended Practice for Hot Weather Concreting, 305-72. A maximum evaporation rate of 0.15 to 0.20 lb/ft^2/hr is recommended.

For cold weather construction, most specifications have either adopted a 45°F minimum for placing LMC or follow ACI 306-66, Recommended Practice for Cold Weather Concreting.

FIELD PERFORMANCE

Although the construction practices for LMC have remained fairly constant over the years, research into one of LMC's

TABLE 2 PERMEABILITY OF FIELD-PLACED LMC

Type of Project	Location	Date of Placement	Overlay Thickness Inches	Overlay Age	Permeability Coulombs	Tested By
Bridge	Indiana	11/83	1 3/8	5 months	524	FHWA
			1 3/4	5 months	302	FHWA
			1 7/8	5 months	346	FHWA
			1 3/8	5 months	257	FHWA
			1 1/2	5 months	214	FHWA
			1 1/4	5 months	323	FHWA
			1 1/2	5 months	285	FHWA
			1 3/4	5 months	274	FHWA
			1 1/2	5 months	419	FHWA
			1 1/2	5 months	310	FHWA
Bridge	Pennsylvania	1978	1 7/8	6 years	243	Dow
			1 7/8	6 years	215	Dow
			1 3/4	6 years	366	Dow
			1 5/8	6 years	160	Dow
			1 7/8	6 years	249	Dow
			2	6 years	104	Dow
			1 7/8	6 years	269	Dow
Parking Garage	Pennsylvania	Summer 85	2	4 months	619	Dow
			2	4 months	538	Dow
Bridge	Washington	unknown	2	5 months	260	Dow
			2	5 months	260	Dow
Bridge	Illinois	1982	2	4 years	287	Dow
			2	4 years	277	Dow
Bridge	Illinois	1982	2	4 years	433	Dow
			2	4 years	441	Dow
Stadium	Illinois	1981	2	3 years	48	Dow
			2	3 years	65	Dow
			2	3 years	43	Dow
			2	3 years	65	Dow
			2	3 years	26	Dow
Parking Garage	North Dakota	unknown	2	2 years	397	Dow
			2	2 years	379	Dow

NOTE: All samples were 2" thick when tested; therefore some samples contained conventional deck concrete.

TABLE 3 WEAR RESISTANCE OF LMC OVERLAY ON THE MARQUAM STREET BRIDGE, OREGON, AFTER 3 YRS OF SERVICE

	average of all wheelpaths for 2 lanes	average of all wheelpaths for 2 lanes	average of all wheelpaths for 3 lanes
		Upper level	
Total ADT[1]	26,600	21,200	47,800
Avg. Wear Rate[2]	0.013	0.019	0.034
Projected Life[3], yrs	40-100	40-59	13-43
		Lower level	
Total ADT[1]	20,200	15,400	35,600
Avg. Wear Rate[2]	0.028	0.038	0.042
Projected Life[3], yrs	23-45	24-40	13-36

[1]Average daily traffic

[2]in/yr/10,000ADT

[3]Based on 1" wear; varies with each wheelpath

most important properties has been stimulated by the advent of the Rapid Permeability Test (*5*). Concrete prepared and cured in the field has been evaluated by this test. The results are given in Table 2.

From these data, it can be seen that the permeability of LMC in the field is well within the criteria established in the initial evaluations of the test method (Table 1).

Other properties of field-cured LMC have been reported recently by the Virginia Transportation Research Council (*3*, *7*). In 1986, the Oregon Department of Transportation measured the wear characteristics (*2*) of the LMC overlay on the Marquam Street Bridge in downtown Portland. Using a straight edge, the department measured the wear in each lane at several locations and then projected a lifetime of the overlay based on time to achieve 1-in. wear. The results (Table 3) indicate a life expectancy of 13–100 yr, depending on the traffic exposure.

The state of Ohio has installed more than 1,500 LMC overlays during the past 14 yr. Recently the state has been conducting condition surveys of these overlays, assigning four ratings: good, fair, poor, and critical. In 1987, the state reported that 74 percent of these LMC overlays were in good condition; 14 percent, fair; and only 2 percent, poor. None were critical.

Another state that has a long history of LMC overlays is Indiana. This history, combined with an intensive effort to inspect and evaluate its bridges, has led the state to the following conclusion: ". . . these overlays have given good service and, with maintenance, the overlays should have a service of life of about 20 years."

ACKNOWLEDGMENT

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