Restoring Skid Resistance to Concrete Pavements and Bridge Decks Using a Latex-Modified Portland Cement Slag Slurry

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The functional life of concrete pavements and bridge decks is frequently reduced by a loss of skid resistance from traffic rather than from structural deterioration of the concrete. By using the bonding capabilities of latex modification, a thin application of a latex-modified portland cement slag slurry has been used to restore skid resistance to concrete pavements and bridges decks, thus extending their useful life in the absence of other types of distress. Applications of this technique in Virginia are described.

For providing good skid resistance, pavements and bridge decks must have adequate microtexture and macrotexture (ASTM E867-89). A sharp microtexture is required to provide friction between the tire and the surface. A deep macrotexture is required to drain water from the surface so that friction can occur between the tire and the high points of the surface and so that hydroplaning can be avoided.

In Virginia before 1970, one pavement and many bridge decks were constructed with aggregates such as limestone and dolomite that polish rapidly when subjected to traffic (ASTM D3319-83). In the 1970s, new pavements and decks were constructed with polish-resistant aggregates such as siliceous, basalt, and granite; new decks were also constructed with latex-modified concrete overlays (with a minimum thickness of 1.25 in.) that contained polish-resistant aggregates. Older decks, particularly those suffering from corrosion-induced distress, were rehabilitated with similar latex-modified concrete overlays that contained polish-resistant aggregates providing adequate microtexture.

In the late 1970s, it was recognized that new pavements, decks, and overlays should be grooved to provide adequate macrotexture (*1*). Grooves approximately ⅛ in. wide by ⅛ in. deep and spaced at approximately ¾ in. on center were applied to the pavement or deck by dragging a tining device across the surface of the plastic concrete before placing the curing materials (*2*). In 1984, diamond grinding was used to restore the skid resistance of the one pavement constructed with polishing aggregate, but the skid numbers dropped rapidly as the aggregate polished. In 1989, shotblasting was used (as an experiment) to temporarily restore the skid resistance of two 300-ft sections of this pavement.

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In the latter part of 1989, because of problems with obtaining a uniform tined texture on decks constructed with concrete mixtures having a low water-to-cement ratio and because the tining operation delayed the application of the curing materials (thereby causing an increase in the incidence of plastic shrinkage cracking), grooves were sawcut into the surface of decks cast full depth and into overlays on decks after the concrete had cured for a minimum of 14 days (*3*).

A latex-modified slag slurry was applied (as an experiment) in Virginia in 1989 and 1990 to increase the skid resistance of the older pavement, and a bridge deck was constructed with polishing limestone aggregate and insufficient macrotexture. The surfaces had lost their microtexture but were not otherwise distressed. The technique was first used in Indiana in September and October of 1980 and later used in San Juan, Puerto Rico, in October and November of 1986 (*4* and C. Pelton, personal communication).

The installation in Indiana may be described as follows (*4*). The applications were placed on SR37 just ahead of a traffic signal at the intersection with SR144 approximately 10 mi south of Indianapolis. Shotblasting, sandblasting, rotomilling, and wet brooming were used to prepare five 350- by 12-ft test sections in each of the two lanes of the concrete pavement. The latex-modified slag slurry was placed on seven sections with a slurry seal applicator modified with oscillating scrub brushes that brushed the slurry into the surface. A water truck and hose were used to wet the pavement ahead of the placement. The slurry was mixed with a mortar mixer of 6-ft^3 capacity that was pulled behind a truck loaded with ingredients. The mixture consisted of 94 lb of portland cement, 244 lb of boiler slag (passed through a 3/16-in. sieve), 38 lb of 48 percent solids latex emulsion, and 22 lb of water. One application was made with expanded shale rather than slag, and no slurry was placed on a rotomilled test section in each lane. The slurry was opened to traffic after 24 to 48 hr of curing.

Skid tests done at 40 mph in October 1980 produced skid numbers in the 50s and 60s for the test sections covered with slag, in the 50s for the sections that were rotomilled but not overlaid, and in the teens for the untreated surfaces. Skid tests done 3 years later, in October 1983, produced skid numbers in the 40s and 50s for the test sections covered with slurry and those that were rotomilled.

The final report on the project recommends the use of shotblasting or sandblasting for surface preparation because no spalls were noted after 3 years in service. Also, the report recommends the use of boiler slag because it provides the highest skid numbers. (The installations on SR37 had been preceded by the hand application of 14 different materials on a low-volume concrete pavement in the Spring of 1978, which was monitored for 2½ years.) Finally, the report recommends against the use of rotomilling for surface preparation because it damages the concrete surface. The test sections were overlaid with asphalt in 1985 because of complaints from the public about the appearance. The test sections covered with slag were still bonded and providing acceptable skid numbers (K. Kercher, personal communication).

The following description of the installation in Puerto Rico is based on a phone conversation with the contractor (C. Ando, personal communication). The slurry in Puerto Rico was applied in October and November 1986 to approximately 6 lane-miles of two- and four-lane jointed concrete pavement and five bridge decks and approaches that had low skid numbers. The first step of the installation involved grinding the concrete surface to remove ⅛ to ¾ in. of the top surface to clean the surface and to restore the surface profile. A rotomill with a 9-ft-wide triple-head-block carbide-tipped drum was used to grind the surface at a rate of approximately 300 ft^2/min (C. Latham, personal communication). The grinding operation was followed by a cleaning operation in which the surface was blasted with high-pressure water to remove the fine cuttings and the cement paste. Typically, the grinding and cleaning operations preceded the application of the slurry by 2 or 3 days, and traffic was allowed to use the cleaned surface. Just before placing the slurry, the surface was lightly cleaned again with high-pressure water to remove contaminants, particularly in the wheel paths. A vehicle equipped with two mortar mixers and a slurry paving box was used to apply the slurry. The ingredients were added to the mixers by hand as follows: 1 bag of portland cement, 245 lb of slag, 38 lb of latex emulsion, and 22 lb of water. The slag was passed through a No. 8 sieve before being used. A light fog mist was applied to the surface from the front of the vehicle. The slurry was applied at night when the air temperature was typically in the 70s. The slurry was opened to traffic after 24 to 36 hr initially, and as the work progressed, it was opened to traffic in 12 hr with the exception of one section that was opened after only 6 hr of cure.

The following summary of the performance of the installation in Puerto Rico is based on telephone conversations with the contractor and the FHWA representative responsible for the application (C. Pelton and C. Ando, personal communications). Within the first 6 months, approximately 0.5 percent of the slurry had delaminated. After 4 years, approximately 1 percent had delaminated and the base concrete was showing in places in the wheel paths. The wear can be attributed to the high volume of traffic.

According to the contractor, the delaminations in the pavement are confined to the joints between the 20-ft sections and can be attributed to a failure to sawcut the slurry over the joints. The delaminations on the bridge decks can be attributed to the shallow cover over the top mat of rebar that would not allow the grinder to remove much concrete from some surfaces. Plastic shrinkage cracks in the decks have not reflected through the slurry (C. Ando, personal communication).

According to the FHWA representative, the delaminations were caused by incomplete surface preparation, applications that were too thick, and mixtures that were not properly proportioned. These problems were greater than usual because the slurry was placed at night during the rainy season and because the contractor was hastening the application to finish before Thanksgiving holiday traffic arrived. Areas that received a proper application are still performing (C. Pelton, personal communication).

OBJECTIVES

The objectives of this paper are to describe the application and initial performance of a latex-modified slag slurry used in Virginia to increase the skid resistance of a pavement and a bridge deck.

APPLICATION OF LATEX-MODIFIED PORTLAND CEMENT SLAG SLURRY

Air-cooled blast furnace slag having a gradation similar to an ASTM C33 concrete sand (see Table 1) was used in the slurry mixtures. However, the slag used on the bridge deck was first passed through a No. 8 sieve. Material that passed the sieve was used in the mixture (see Table 2), and material that was retained was broadcast onto the freshly placed slurry at the rate of 5 lb/yd^2 to provide additional microtexture and macrotexture. The slag was obtained from Ducan Slag Products Company in Pittsburgh, Pennsylvania. The details of the applications are presented in Table 3.

Before the slurry was placed, the surfaces were shotblasted to remove dirt, oil, weak surface mortar, and materials that could interfere with the bonding or curing of the slurry. Some surfaces were prewet before the slurry was placed, and some were not. The slurry was batched with a concrete mobile and brooms were used to brush the latex-modified slag slurry into the surface (see Figure 1). For the bridge deck applications, the slurry was struck off and pulled forward with gage rakes set to provide a slurry 3⁄16 to ¼ in. thick. For increased skid resistance, slag retained on the No. 8 sieve was broadcast onto the struck-off surface. A liquid membrane curing material was also applied. Because the gage rakes, broadcast of aggregate, and liquid membrane curing material were not used on the 300-ft pavement application, the surface was uneven, provided a rough ride, and was not pleasing to the eye.

MECHANICAL PROPERTIES OF LATEX-MODIFIED SLAG SLURRY

Compressive Strength

The slurry must cure for at least 24 hr to obtain adequate strength (1,000 psi compressive strength) for traffic (see Table 4). A slag slurry mixture made with a special blended cement of high early strength should be evaluated for use when a short lane closure time is required.

TABLE 1 SIEVE ANALYSIS OF SLAG (PERCENT PASSING INDICATED SIEVE)

Sieve	Slag	ASTM C33
3/8	100	100
4	95	95-100
8	63	80-100
16	39	50-85
30	24	25-60
50	16	10-30
100	9	2-10
200	4	—

TABLE 2 MIXTURE PROPORTIONS FOR LATEX-MODIFIED PORTLAND CEMENT SLAG SLURRY (lb/yd^3)

	Design[a]	Actual[b]
Cement[c]	791	811
Slag[d]	2,062	2193
Latex emulsion	320	328
Water	185	115
W/C	0.44	0.35

[a]Assuming 3% void content.
[b]The slag was assumed to have an 8% moisture content, but was found to have an 11% moisture content. A correction for absorption was not made.
[c]Type III portland.
[d]Specific gravity = 2.34
Mohs scale hardness = 5.5
Sodium Sulfate = 4%
Absorption = 6.89

TABLE 3 LATEX-MODIFIED SLAG SLURRY APPLICATIONS

	Pavement Travel Lane I-81 NBL Botetourt Co.	Deck Passing Lane I-81 NBL over 679 Rockbridge Co. Structure No. 2016	Deck Travel Lane I-81 NBL over 679 Rockbridge Co. Structure No. 2016
Size	300 ft x 12 ft	204 ft x 12 ft	204 ft x 12 ft
Date shotblasted	5/17/89	10/31/89	4/26/90
Date slurry applied	5/17/89	10/31/89	4/26/90
Time slurry applied	3:30 - 4:30 p.m.	—	10:00 - 11:30 a.m.
Weather	Sunny	—	Sunny
Air temperature,°F	82°F	—	86°F
Date opened to traffic	5/19/89	—	4/28/90
Age opened to traffic	42 hrs	4 wks	48 hrs

FIGURE 1 A latex-modified slag slurry overlay is applied to a bridge deck to increase the skid resistance.

Bond Strength

The average tensile rupture strength (American Concrete Institute 503R) of the slurry overlay placed on the passing lane of the bridge was measured on November 13 at an age of 13 days and found to be 260 lb/in.^{2} for the average of six tests (*5*). Because the majority of the failure was in the base concrete, the bond strength could be assumed to be greater than 260 lb/in.^{2}. Although a few small areas have spalled in the concrete pavement, no spalls have occurred on the bridge deck. Also, few cracks have been noted.

Skid Numbers at 40 mph

Skid tests were conducted at 40 mph using a smooth tire (ASTM E524-88). The minimum acceptable skid number in

TABLE 4 COMPRESSIVE STRENGTH (lb/in²) VERSUS AGE FOR OVERLAYS

	Latex-Modified Slag Slurry Test Section	
Age	I-81 NBTL pavement	I-81 NBTL bridge deck
18 hr	370	—
24 hr	—	1,050
40 hr	1,970	—
48 hr	—	1,590
28 day	4,100	2,680

Results based on average of three tests on 2-in field cured mortar cube specimens.

Virginia is 20. New surfaces should have skid numbers much higher than 20 because the numbers decline as the cumulative traffic over the surfaces increases (*6*).

The bridge deck and pavement constructed in the 1960s with polishing limestone aggregate and a screeded surface exhibited skid numbers of 17 and 27, respectively, before the slurry was placed. Several months after the slurry was placed, the average skid numbers were 39 and 65, respectively. A higher skid number was obtained for the pavement because the macrotexture was greater. An adequate skid number was obtained for the bridge deck, and the application to the deck was smoother and more pleasing to the eye.

COST

The cost of the latex-modified slag slurry was $5.90/yd², which was higher than the $2.50/yd² to $3.50/yd² cost of shotblasting, diamond grinding, and rotomilling; it is about the same as the cost of sawcut grooves; and it is very low compared to the $35/yd² cost of a latex-modified concrete overlay (of minimum thickness 1.3 in.).

SERVICE LIFE

The service life cannot be determined at this time; it will likely be a function of the type and volume of traffic. On the basis of the experiences in Indiana and Puerto Rico, a life in excess of 5 years seems likely for high-volume roads.

ADVANTAGES OF LATEX-MODIFIED SLAG SLURRY

The applications in Indiana, Puerto Rico, and Virginia illustrate that a latex-modified slag slurry can be placed on pavements and bridge decks to provide adequate surface texture. One advantage of the slag slurry is increased cover over the top mat of rebar in decks as compared with the sawcutting of grooves, shotblasting, diamond grinding, and rotomilling for skid resistance. Another advantage of the latex-modified slag slurry is that new decks and pavements can be constructed with polishing aggregates, thereby extending the diminishing supplies of aggregates. The slurry can also be applied to provide adequate skid resistance. Tining the plastic concrete and sawcutting grooves in the hardened concrete are not acceptable methods for increasing skid resistance when decks or pavements are constructed with polishing aggregates because the surface does not have adequate microtexture. A final advantage is the high microtexture and adequate macrotexture at a low cost compared with 2-in.-thick portland cement concrete overlays, 1.25-in.-thick latex-modified concrete overlays, and 0.25-in.-thick polymer overlays. However, the latter types of overlays are usually applied to decks constructed with black steel to retard the infiltration of chloride ion.

SPECIAL PROVISION

A Virginia Department of Transportation special provision that was prepared on the basis of the experimental applications follows.

1. Description. This work shall consist of preparing and shotblasting concrete surfaces and furnishing and applying latex portland cement slurry in accordance with this specification and in reasonably close conformity with the lines, grades, and details shown on the plans or established by the engineer.

2. Materials. Latex portland cement slurry shall conform to the requirements of Section 219 of the *Specifications* except that the maximum water per pound of cement shall be 0.45 lb, and the design minimum laboratory compressive strength shall be 3,000 psi. Latex portland cement slurry shall have a mix design similar to:

Ingredient	*Density, lb/yd³*
Type III portland cement	791
Air-cooled blast furnace slag	2,062
Latex emulsion	320
Water	185

The air-cooled blast furnace slag shall have a gradation similar to ASTM C33 and shall be passed through a No. 8 sieve. Blast furnace slag that passes through the sieve shall be used in the latex portland cement slurry. Blast furnace slag retained by the sieve shall be broadcasted on the surface of the latex slurry at a rate of 5 lb/yd².

3. Construction. Section 416.09 of the *Specifications* is completely replaced by the following sequence of operation:

1. Close one lane.
2. Shotblast deck surface in closed lane.
3. Air-blast the deck surface to remove loose material.
4. Apply latex slurry.
5. Broom latex slurry into the surface.
6. Level latex slurry with gage rakes.
7. Broadcast slag onto surface of latex slurry.
8. The slurry shall be protected from drying by prompt

application of wet burlap and polyethylene when the evaporation rate exceeds 0.05 lb/ft^2/hr as determined using the chart shown as Figure 1 in the ACI standard practice for curing concrete (ACI 308). The burlap and polyethylene shall be removed after 24 hr of curing.

9. Once proper compressive strength has been attained, open lane to traffic and begin operation in the other lane with Number 1.

One lane of a structure shall be closed at night or early morning; shotblasting shall be completed and latex slurry applied by noon of the same day.

a. Surface Preparation. The contractor shall shotblast the deck to remove material detrimental to the bonding of the latex slurry. The shotblasting equipment shall not be operated at a rate that exceeds 12 yd^2/min. The contractor shall verify the results of shotblasting by performing sandpatch tests in accordance with ASTM E965. One test must be conducted on each 100 yd^2. For areas of less than 400 yd^2, four tests must be conducted. The macrotexture depth shall be greater than or equal to 0.03 in. for each test. If the required depth is not obtained, the contractor shall shotblast the deck and conduct tests until an adequate macrotexture is obtained.

Deck drains and expansion joints shall be protected from latex slurry's being applied to or passed through. The protective coverings of deck drains and expansion joints shall be removed after latex slurry has cured sufficiently.

At least 1 hr before the application of latex slurry, the deck shall be thoroughly moistened with water. All puddles of water shall be removed in an approved manner so that the deck is in a saturated surface dry condition before the application of latex slurry.

b. Placing and Finishing Latex Slurry. Latex slurry shall be applied in accordance with Section 404 of the *Specifications* and as stated herein.

In addition to the ambient air temperature requirements in Section 404.16, the latex slurry shall not be applied when the surface temperature of the deck exceeds 90°F.

Latex slurry shall be leveled by pulling adjustable gage rakes parallel to the direction of traffic, and the slurry shall be 3⁄16 to 1⁄4 in. thick.

Precautions shall be taken to protect freshly placed latex slurry from rain. All placing operations shall stop when it starts to rain. The engineer may order the removal of any material damaged by rainfall.

The lane shall be kept closed until 2-in. mortar cubes cured at the site obtain a compressive strength that exceeds 1,000 psi.

4. Method of Measurement and Basis of Payment. Latex portland cement slurry will be measured in square yards of surface area. Latex portland cement slurry will be paid for at the contract unit price per square yard, which price shall be full compensation for shotblasting the deck; for furnishing, placing, and finishing latex slurry; for disposal of unsound and contaminated concrete, and for all materials, labor, tools, equipment, and incidentials necessary to complete the work.

Payment will be made under the Pay Item latex portland cement slurry with Pay Unit in square yards.

CONCLUSIONS

The application of a latex-modified portland cement slag slurry has potential to be an economical technique for increasing the microtexture and macrotexture of hardened concrete surfaces constructed with polishing aggregates and not otherwise distressed. It can also be used as an alternative to grinding, rotomilling, shotblasting, and sawcutting grooves on hardened concrete surfaces constructed with polish-resistant aggregates. The technique is limited to pavements and bridge decks that can be closed for at least 1 day to allow for proper cure.

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