Use of High Molecular Weight Methacrylate Monomers To Seal Cracks in Bridge Decks, Retard Alkali-Silica-Aggregate Reactions, and Prime Bridge Surfaces for Overlays

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Presented are the results of a study undertaken to evaluate the performance of high molecular weight methacrylate (HMWM) monomers used to (a) treat the cracks and seal the surfaces of two tined bridge decks, (b) seal the surface of one untined bridge deck, (c) fill the cracks and seal the surface of a pavement to retard an alkali-silica-aggregate reaction, and (d) prime the surface of a bridge deck for a polyester styrene concrete overlay. For the two tined bridge decks, the evaluation was based on data collected during application, skid tests, permeability tests on cores removed from decks, petrographic examination of the cracks in the cores, and inspections of the decks for leaks. The evaluation indicated that no significant problems were associated with the application and that the treatments partially filled the top ½ in. of the cracks. However, because of traffic- and temperature-induced strains across the cracks, the polymer in many of the treated cracks was cracked after 1 year in service. Even so, the treatments significantly reduced the permeability to chloride ions of the top 2 in. of both the cracked and uncracked sections of the decks. The permeability of cores taken from treated cracked and uncracked areas after 1 year was 59 and 43 percent, respectively, of the permeability of the untreated bases. After 3 years, the permeability was 64 and 42 percent, respectively. Study results indicate that applying HMWM monomers is a practical way to reduce the infiltration of chloride ions into concrete surfaces with cracks that are wider than 0.15 mm because of the low cost and ease with which the treatment can be applied as compared with a pressure injection of epoxy. Results also indicate that HMWM monomers can be applied as a prime coat to improve the bond strength of polyester styrene concrete overlays.

Cracks in concrete can provide water and salt easy access to reinforcement, which can cause premature corrosion. The use of an injection of epoxy to seal cracks is costly and time-consuming; therefore, a more economical method of sealing cracks is needed. High molecular weight methacrylate (HMWM) monomers can be applied to the surface of a bridge deck to seal the concrete and fill and seal the cracks (*1–7*). The application is a simple process that does not require specialized pressure-injection equipment. Typically, a promoter and an initiator are mixed with the monomer, and the monomer is applied to the cracked surface with a broom or squeegee. Aggregate is usually broadcast onto the monomer to provide for adequate skid resistance. When cracks are not closely spaced, the monomer can be applied only to the cracks, without covering the entire deck surface.

The California Department of Transportation applied HMWM monomers to seal cracked and deteriorated concrete in bridge decks, retard alkali-aggregate reactivity, and prime surfaces before placing a premixed polyester overlay (*1,7*). HMWM monomers have been used to seal cracks in a bridge in Texas (*1*), a bridge in Iowa (*2*), and a bridge in Florida (*3*), and to extend the life of a continuously reinforced concrete pavement in South Dakota that was spalling because of an alkali-silica-fine aggregate reaction (*4*).

The Virginia Department of Transportation (VDOT) has also used HMWM monomers on bridge decks (*6*). Tests for recracking strength and filling conducted on concrete specimens prepared in the laboratory indicated that HMWM monomers can be successfully used to seal cracks of variable widths (0.2 to 2.0 mm) and moisture content (*5*).

BACKGROUND

A demonstration conducted in 1987 showed that a simple application of an HMWM monomer was as effective in sealing some cracks in the tined deck of a bridge on I-81 in Virginia as a vacuum injection of methacrylate and was more effective than a pressure injection of epoxy (*8*). Although none of the three treatments successfully filled the cracks (typically 0.1 to 0.2 mm wide), a low-modulus HMWM monomer (Rohm & Haas PCM 1680) filled approximately 50 percent of the volume of the cracks in the top 4 in. of the deck. It is believed that a factor in the relative success of using the HMWM monomer was the time of application—it was applied in the early morning when the cracks were open. Because of the time required to prepare cracks for injection, injections of the other materials were not performed until the afternoon, when the cracks were closed. The HMWM monomer was selected to treat the cracks in the deck because of the anticipated low cost: approximately $1/ft, compared with approximately $6/ft for routing and sealing with a low-modulus epoxy, $20/ft for a pressure injection of epoxy, and $40/ft for a vacuum injection of methacrylate (*6*). In addition, the entire deck

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surface could be sealed with the HMWM monomer for about $1/ft².

A meeting was held by VDOT to obtain the input necessary from FHWA and industry representatives to draft a special provision for the treatment of the cracks in the decks of the bridges on I-81 (*6*). Because it had been noted during the demonstration that a small amount of the HMWM monomer had leaked through the cracks into the New River, the special provision required that the contractor protect traffic, waterways, and bridge components from the monomer. It is believed that the unit price for the treatment was high because of this requirement, which made it necessary for the contractor to work on the underside of the deck to seal the cracks or collect the drips.

At least five companies market an HMWM monomer for use in treating cracks. Four were noted elsewhere by Sprinkel (*6,8*), and the fifth, Transpo Industries, Inc. (New Rochelle, New York), supplied the T-70-M and T-70-X monomers that were used. Unfortunately, data on the physical properties of HMWM monomers and concrete are limited, and recommendations for applications differ as a result of the recent development of the monomers. Therefore, it was necessary to collect the data needed to revise the special provision to prescribe the physical properties of the monomers and the application requirements for future installations. The literature from the five manufacturers stated that each could provide an HMWM monomer with a viscosity of 8 to 25 cps (Brookfield Model LVT Viscometer, Spindle 1 at 60 rpm), specific gravity of 1.02 to 1.08 at 77°F, low odor, bulk cure in less than 3 hr at 73°F, surface cure in less than 8 hr at 73°F, and gel time of 20 to 50 min.

PURPOSE AND SCOPE

The purposes of this paper are as follows:

1. Describe the application of two HMWM monomers on two tined bridge decks, the condition of the cracks immediately following the treatments and 1 and 3 years after installation, and data on the physical properties of the monomers (*6*). The evaluations were based on skid tests (ASTM E524), permeability tests on cores (AASHTO T277), petrographic examination of cores taken from cracks, and periodic on-site inspections of the underside of the decks for leaks.
2. Describe the results of using an HMWM monomer to seal an untined bridge deck.
3. Describe the results of using an HMWM monomer to fill cracks and seal the surface on a section of I-64 to retard an alkali-silica-aggregate reaction.
4. Describe the results of using an HMWM monomer as a primer for a polyester styrene concrete overlay for a bridge deck.

RESULTS

Tined Bridge Decks on I-81

Description of Application

The two bridges are continuous-span, steel-plate-girder bridges constructed with prestressed concrete subdeck panels and composite, site-cast concrete decks (*6*). Each bridge has five plate girders and 10 spans. The southbound travel lane (SBTL) was opened to traffic in September 1985 and the northbound travel lane (NBTL) in September 1986. Transverse cracks were observed in both decks in 1986 directly above the joints between the subdeck panels. Longitudinal cracks were observed above the girders.

Cracks in two spans treated with a high-modulus HMWM monomer (T-70-M) and cracks in two spans treated with a low-modulus HMWM monomer (T-70-X) were evaluated. The application of the two HMWM monomers was performed in accordance with the special provision (*6*) that required the contractor to protect traffic, waterways, and bridge components from the monomer. To satisfy this requirement, the contractor suspended polypropylene tarpaulins under the decks from the parapets on each side of the bridges. By using the tarpaulins to catch drippings, it was not necessary to caulk or seal the cracks on the underside of the decks. According to the contractor, no monomer dropped onto the tarpaulins.

The special provision also required that the concrete surface and the cracks be blasted with oil-free compressed air to remove dirt, dust, and other loose material before application of the monomer. Finally, the special provision required that the monomer be applied between 1 a.m. and 11 a.m. at a deck surface temperature between 55°F and 70°F. According to the inspector, the monomer was applied between sunrise and 11 a.m. at a deck surface temperature between 51°F and 70°F. On many days, the application was stopped before 11 a.m. because the deck temperature had reached 70°F (*6*).

Each monomer was mixed in 1- or 2-gal batches and poured into 2-gal spray cans that were used to apply it to the cracks. HMWM monomer gels rapidly when contained in large quantities, and therefore 1 gal or less of mixed monomer was placed in a spray can. The monomer was applied to the cracks at the rate of 200 ft/gal. According to the inspector, many spray cans became inoperable because the monomer gelled in the nozzle or in the line between the nozzle and the container. The special provision required three applications to each crack. However, because of the narrow width of many of the cracks and because the first application tended to seal the top of the cracks, only the wider cracks received more than one application. As can be seen in Figure 1, the deck surface within 3

FIGURE 1 HMWM monomer applied to cracks in tined bridge. To maintain good skid number, excess resin in valleys must be broomed over deck surface before it gels.

in. of a crack was usually treated with the resin. When too much resin was applied to a crack, the excess resin was brushed over the deck surface before it gelled so that the grooves were not filled.

Once the cracks were filled, the monomer was applied to the deck surface to seal the concrete and bring the color of the deck surface between the cracks close to the color of the surface in the vicinity of the cracks. The monomer used to seal the deck surface was mixed in 5-gal batches and applied with an airless sprayer (see Figure 2).

The monomers were supplied by Transpo Industries, Inc. and applied by Academe Paving, Inc. The application was initiated on May 10 and completed on June 2, 1988, with no significant problems. Only 13 workdays and 17 days of lane closure were required for the $271,496 contract. The cost was as follows:

- Traffic control: $39,538 (14.6 percent),
- Crack sealing: 15,000 ft @ $2.97/ft + 226 gal HMWM @ $85.20/gal = $63,805 (23.5 percent), and
- Deck treatment: 125,656 ft² @ $0.77/ft² + 838 gal @ $85.20/gal = $168,153 (61.9 percent).

Mechanical Properties of HMWM Polymer Specimens

The mechanical properties of the HMWM polymer specimens are presented in Table 1. The 2-in. cube specimens of T-70-X and T-70-M were molded at the job site using an ASTM C33 concrete sand. The sand/monomer ratio was approximately 4.5 to 1 by weight. Some of the neat tensile specimens were molded at the job site, and some were molded in the laboratory of VDOT's Materials Division. Subsequent to the treatment of the decks on I-81, other HMWM monomers were evaluated. Data for specimens of RPM-1100-V polymer that were molded at the materials laboratory and at a pavement job site (I-64 in New Kent County) are also presented in Table 1.

The data for compressive strength and modulus of elasticity (ASTM C109) shown in Table 1 are typical for cubes of HMWM polymer and sand. The data for tensile strength, elongation at break, and modulus of elasticity (ASTM D638) are typical for very brittle polymers, such as T-70-M, and flexible polymers, such as RPM-1100-V. On-site inspections in June 1988 revealed many cracks in the T-70-M polymer in the deck cracks and few cracks in the T-70-X polymer in the deck cracks. However, it can be seen from the data that the T-70-X polymer lost most of its flexibility within 15 months, which may explain the large increase in the number of cracks in the polymer in the deck cracks after 1 year in service. The T-70-M specimens were too brittle to test after 15 months. Neat cubes of T-70-M made during the installation on I-64 shattered at compressive strengths of less than 3,000 psi when tested at 30 hr and 28 days. On the other hand, neat cubes of RPM-1100-V were compressed 1 in. without failure when tested at 28 days of age. More flexible polymers such as RPM-1100-V should do a better job of sealing cracks that move.

FIGURE 2 Airless spray guns were used to apply HMWM resin to surface of tined bridge deck. Note that work crew is wearing rubber boots and gloves, impermeable coveralls, and canister breathing masks.

Tests on Cores

Cores 4 in. in diameter and approximately 5.5 in. in length were removed from the NBTL of Spans 6 and 7 (treated with T-70-X) and Spans 8 and 9 (treated with T-70-M). Twenty-eight cores were removed in June 1988, and 14 were removed in July 1989. The cores were taken through transverse cracks, longitudinal cracks, and concrete that did not appear to be cracked (see Table 2).

Two 2-in.-thick slices were cut from each core. One slice was cut from the top 2 in. of each core ("top" in Figure 3), and the second slice was cut at a depth of 2 1/8 in. to 4 1/8 in. from the top surface ("base" in Figure 3). In 1988, the cores were taken in pairs approximately 2 ft apart along cracks selected for evaluation. Two slices from one core in each pair were subjected to rapid permeability tests, and two slices from the other core were subjected to a tensile splitting test.

After the rapid permeability tests were conducted, a slice ¾ in. thick, 2 in. wide, and approximately 4 in. long was cut from each permeability specimen. The slice was cut in the vertical plane and perpendicular to the crack in the specimens with the cracks (see Figure 3). Both surfaces were polished and examined under the microscope so that the width of the crack could be measured as a function of depth and so that the percentage of the crack width that was filled with HMWM monomer could be recorded as a function of depth. Forty-eight cracked surfaces were examined in 1988; none were examined in 1989.

The two segments that were left after the center slice was cut from each permeability specimen were subjected to a flexural test. A total of 56 specimens were tested in flexure in 1988; none were tested in 1989.

After the permeability tests on cores taken in 1989, the specimens were subjected to a splitting tensile test, and, therefore, 14 cores did not have to be taken for splitting tensile tests in 1989. The intent of the tests on the cores was to obtain as much information as possible from as few cores as possible.

Permeability to Chloride Ion The results of the tests for the permeability to chloride ion (AASHTO T277) of slices of cores 2 in. thick taken in 1988 and 1989 are presented in Table 3. A value of 1,000 to 2,000 C is considered to represent low permeability; 2,000 to 4,000, moderate; and more than 4,000,

TABLE 1 Mechanical Properties of Specimens of HMWM Polymer

Specimen Type	Age	Strength (psi) $\bar{X}$	Strength (psi) s	Elongation at Break (%) $\bar{X}$	Elongation at Break (%) s	Young's Modulus of Elasticity[a] (lb/in^2 x 10^4) $\bar{X}$	Young's Modulus of Elasticity[a] (lb/in^2 x 10^4) s
T-70-M mortar cubes	2 mo	6,420	660	—	—	24.0	5.5
T-70-M mortar cubes	15 mo	6,500	330	—	—	25.5	2.4
T-70-M mortar cubes	3 yr	6,440	12	—	—	—	—
T-70-X mortar cubes	2 mo	8,000	160	—	—	20.3	2.7
T-70-X mortar cubes	15 mo	8,540	590	—	—	25.5	6.3
T-70-X mortar cubes	3 yr	8,680	176	—	—	—	—
T-70-M neat tensile	7 day	215	106	0.5	0.3	4.40	0.37
T-70-M neat tensile	15 mo	—	—	—	—	—	—
T-70-X neat tensile	7 day	3,036	402	5.4	0.8	5.80	0.47
T-70-X neat tensile	15 mo	881	397	1.3	0.4	6.77	1.05
T-70-X neat tensile	3 yr	447	75	2.1	1.3	3.79	3.48
RPM-1100-V neat cubes[b]	28 day	4,250	350	—	—	—	—
RPM-1100-V mortar cubes	28 day	7,390	14	—	—	—	—
RPM-1100-V neat tensile	7 day	2,900	230	20.2	5.0	—	—

[a]Measured at ≤0.004 in./in. for cubes and ≤0.05 in./in. for tensile specimens.
[b]At 1-in. deflection.

TABLE 2 Tests Conducted on Tined Bridge Cores

Type Crack in Core	Number of Cores Taken 1988	Number of Cores Taken 1989	Permeability Tests 1988	Permeability Tests 1989	Petrographic Examinations 1988	Petrographic Examinations 1989	Flexural Tests 1988	Flexural Tests 1989	Tensile Splitting Tests 1988	Tensile Splitting Tests 1989
Transverse	16	8	16	16	32	0	32	0	16	16
Longitudinal	8	4	8	8	16	0	16	0	8	8
None	4	2	4	4	0	0	8	0	4	4
Total	28	14	28	28	48	0	56	0	28	28

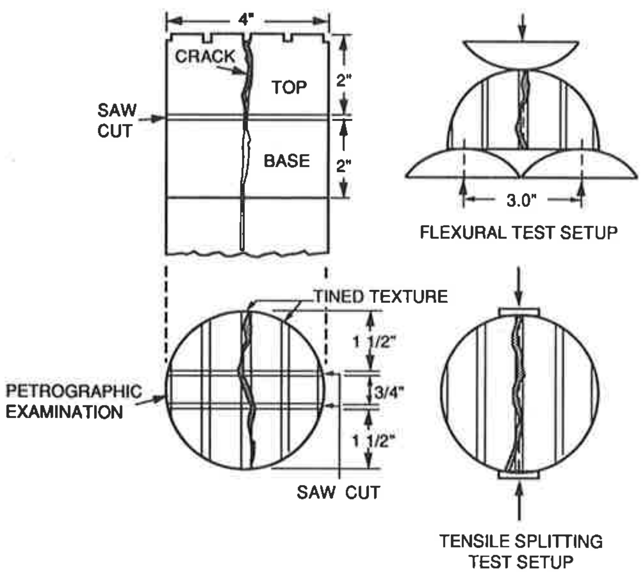

FIGURE 3 Sketch of test specimens obtained from tined bridge cores.

high. The data in Table 3 show that the average permeability of the top 2 in. of the cores taken in 1988 was 44 percent of that of the base concrete, and for cores taken in 1989, it was 52 percent of that of the base concrete. No tests were performed on base concretes in 1991, but the average permeability of the top 2 in. of the cores was 57 percent of the average of the bases tested in 1988 and 1989. The permeability increased after 1 and 3 years in service, probably as a result of traffic wearing away the HMWM coating and cracking the HMWM polymer in the cracks. However, the protection provided by the T-70-X polymer has not changed much in 3 years.

The data in Table 3 also suggest that after 1 and 3 years the permeability of the cracks treated with T-70-M had increased more than the permeability of the cracks treated with T-70-X, which was expected because the T-70-X is more flexible than the T-70-M. In addition, the permeability of the transverse cracks had increased more than that of the longitudinal cracks after 1 year, as was expected because the transverse cracks moved more than the longitudinal cracks. However, after 3 years, the permeability of the longitudinal cracks had also increased. It is not known why the average permeability for the base concrete without cracks was higher than

TABLE 3 Permeability of Tined Bridge Cores to Chloride Ions (Coulombs)

Type Crack	HMWM Monomer	1988 Top 2 in.	1988 Base	1988 Top/Base	1989 Top 2 in.	1989 Base	1989 Top/Base	1991 Top 2 in.	1991 Base	1991 Top/Base
Transverse	Both	1,669	3,528	.47	1,980	2,444	.81	2,187	2,986	.73
Longitudinal	Both	1,373	3,570	.38	1,391	3,612	.39	2,039	3,591	.57
Both	Both	1,570	3,539	.44	1,784	3,028	.59	2,113	3,284	.64
None	Both	1,297	3,850	.34	1,908	4,404	.43	1,718	4,127	.42
All specimens	T-70-X	1,427	3,416	.42	1,496	3,013	.50	1,550	3,215	.48
All specimens	T-70-M	1,635	3,571	.46	2,107	3,960	.53	2,412	3,766	.64
All specimens	Both	1,531	3,497	.44	1,801	3,487	.52	1,981	3,492	.57

the average for the concrete with cracks. The lower permeability of the cracked specimens cannot be attributed to the HMWM monomer because little monomer penetrated the cracks to a depth of 2 to 4 in.

Petrographic Examinations Figures 4 and 5 show the results of petrographic examinations of vertical, polished cracked surfaces obtained by cutting a slice ¾ in. wide from the top 2 in. and next 2 in. of each of 12 cores (see Figure 3). Both cut surfaces were polished and examined under the microscope, and, therefore, 48 surfaces were obtained from 12 cores taken through cracks in 1988. No petrographic examinations were performed in 1989.

Figures 4 and 5 show the average width of the cracks as a function of depth and the average width that is filled with HMWM monomer. The transverse cracks were typically wider than the longitudinal cracks. The following can be seen from Figures 4 and 5:

- Many of the cracks are much wider at the surface than throughout the top 4-in. depth of the deck.
- The cracks are very narrow (less than 0.2 mm), except on the surface.
- The HMWM monomer did not fill the cracks very well at depths greater than 0.5 in. from the surface.
- There is no difference in the performance of the monomers (T-70-X versus T-70-M) from the standpoint of percentage of crack width filled as a function of depth.

Laboratory work (*5*) indicated that the monomer worked well for cracks 0.2 to 2.0 mm wide. It is unlikely that any currently available crack-filling technique would have led to the cracks being filled more because of the narrow width of most of the cracks. Fortunately, the American Concrete Institute (ACI) indicates that cracks up to 0.18 mm wide are tolerable in concretes that are exposed to deicing chemicals and therefore do not need to be sealed (*9*). Because of their low viscosity, penetrating sealers (such as silanes or siloxanes) may have done a better job of sealing the walls of the cracks.

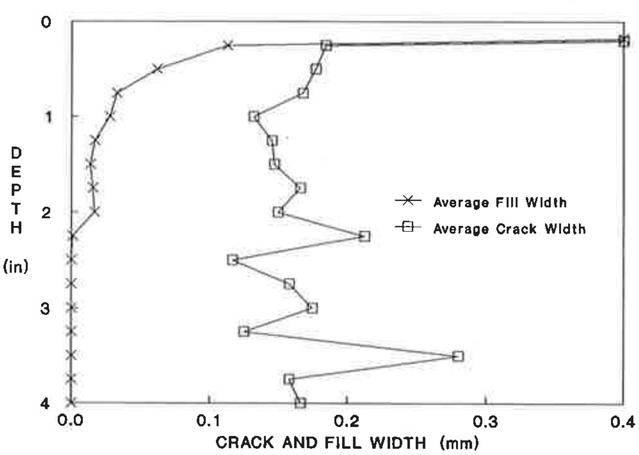

FIGURE 4 Average crack width and crack width filled versus depth (tined bridge), all cracks, Spans 6 and 7 (T-70-X). At surface, average fill width = 1.09 mm and average crack width = 1.26 mm.

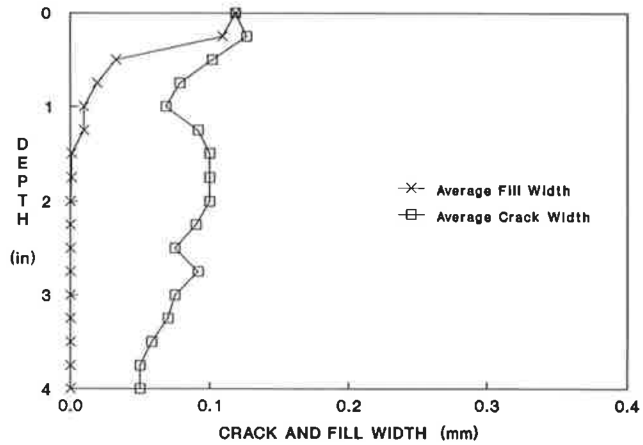

FIGURE 5 Average crack width and crack width filled versus depth (tined bridge), all cracks, Spans 8 and 9 (T-70-M). At surface, average fill width = 0.12 mm and average crack width = 0.12 mm.

To see the relationship of crack width and the percentage of crack width filled, cracks were grouped according to width for each of the depths from the surface for which measurements were made:

- At the surface, most cracks were 95 percent filled, regardless of width.
- At a depth of ¼ in. from the surface, cracks wider than 0.15 mm were 92 percent filled, but cracks 0.15 mm wide or narrower were 44 percent filled.
- At a depth of ½ in. from the surface, cracks wider than 0.15 mm were 57 percent filled, but cracks 0.15 mm wide or narrower were 35 percent filled.
- At depths of ½ in. or more from the surface, the data were too variable to draw conclusions, but most cracks were filled less than 20 percent, and no HMWM polymer was found at depths of more than 2¼ in. However, one crack as narrow as 0.05 mm was 100 percent filled at a depth of 1 in.

Flexural Tests As shown in Figure 3, the portions of the cores that were left after a slice was cut for petrographic examination were subjected to a three-point flexural test to determine the degree to which the HMWM monomer treatment had bonded the sides of the cracks together and restored the flexural strength of the concrete. A modulus of rupture was computed for each specimen using the ASTM C293 formula as follows:

$$R = 1.5\ Pl/bd^2$$

where

R = modulus of rupture,
P = maximum applied load,
l = 3 in.,
b = 2 in., and
d = depth of specimen at point of fracture.

The treatment did not restore the flexural strength of the concrete. The average modulus of rupture was 110 psi for the cracked specimens, compared with 990 psi for the uncracked specimens taken from the top 2 in. of the cores in 1988. The results were expected, considering that the HMWM monomer did not completely fill the cracks (*6*).

The surfaces of the failed specimens were examined to determine the location of the failure. For the cracked specimens, no failures occurred in the concrete, and all failures occurred through the cracks. On the average, 40 percent of the failed surfaces from the top 2 in. of the cores were coated with polymer and 60 percent were coated with dust, road dirt, and carbonation. Of the failed surfaces from the base slices, 100 percent were coated with dust, road dirt, and carbonation, and no polymer was observed. Because of the foreign material in a crack in a structure that is in service, it is unlikely that any crack-filling technique can bond the crack surfaces together unless a technique is developed to clean the surfaces of the crack before the filling operation. The restoration of flexural strength in laboratory specimens (*5*) can be attributed to the fact that the surfaces of the cracks were clean before the treatment because the specimens were fabricated, broken in flexure, put back in molds, treated with HMWM monomer, and broken in flexure a second time. No flexural tests were done on cores taken from the bridge deck in 1989.

Tensile Splitting Tests

In 1988, slices 2 in. thick were cut from one core for each pair of cores taken along a crack and from one-half of the cores taken through uncracked concrete. The slices were subjected to a tensile splitting test as described in ASTM C496 and shown in Figure 3. The specimens were loaded at the rate of 2,000 lb/min, and the tensile splitting strength was computed as $2P/ld$, where P is the applied load, l is 2 in., and d is 4 in. In 1989, tensile splitting tests were conducted on the specimens that had been subjected to the rapid permeability test because the specimens were not needed for petrographic examinations and flexural tests. Test specimens with an l/d ratio of at least 1 as required by ASTM C 496 could not be tested because the HMWM did not fill the cracks at depths greater than 2.0 in.

Similar values in the range of 420 to 670 psi were found for the cracked and uncracked specimens in 1988 and 1989, which suggests that the HMWM monomer restored the tensile strength of the concrete across the crack. However, this result is not supported by the petrographic examinations or the flexural test results. Evidently, the test subjected the cracked surfaces to shear instead of tension, and there were enough irregularities between the surfaces that shear stresses were transferred as well as in the uncracked concrete. Approximately 30 percent of the failures in the cracked specimens occurred in the concrete in 1988 and 1989. The failures that occurred through the cracks provided surfaces that were coated with polymer, dust, road dirt, and carbonation.

Skid Resistance

Skid tests were conducted at 40 mph using the bald tire (ASTM E524) and the treaded tire (ASTM E501). Tests were done with the bald tire in the summer of 1988, following the treatments, and with both tires in 1989. As can be seen from the data in Table 4, the treated surfaces have an acceptable skid resistance. The acceptable skid resistance (bald tire numbers greater than 20) can be attributed to the tined texture of the deck surface and the fact that the HMWM monomer did not fill the valleys in the texture. The application of sand (1 lb/yd^2) may have had a minor effect.

Visual Inspections

The inspector made visual inspections of the underside of the bridges during periods of rain for 1 year following the treatments. According to the inspector, some leaks were noted on Spans 6–9 of the NBTL, but he attributed the leaks to the holes caused by taking cores from the deck. An inspection by the author in the spring of 1989 revealed efflorescence next to the joints between the subdeck panels on approximately 50 percent of the joints on the NBTL. Very little efflorescence was noted on the underside of the deck on the SBTL. The efflorescence was more prevalent in the negative moment areas, as was expected. There was not a clear difference between the quantity of efflorescence under Spans 6 and 7 as compared with Spans 8 and 9. The design of the continuous-span structure and the large amount of deflection under traffic likely accelerated the cracking of the polymer in the cracks.

Untined Bridge Deck

Rohm & Haas PCM 1100 and 1500 monomers were applied to the eastbound lane of two spans of an untined bridge on Route 601 over Polecat Creek in June 1986. Approximately

TABLE 4 Skid Numbers at 40 mph in Travel Lane

Structure	Spans	HMWM Treatment	Sand Application (lb/yd^2)	Skid Numbers: Treaded Tire 1987	Treaded Tire 1989	Bald Tire 1987	Bald Tire 1988	Bald Tire 1989
I-81 Deck	6 & 7	T-70-X[a]	1	—	48	—	36	36
I-81 Deck	8 & 9	T-70-M[a]	1	—	45	—	37	35
I-64 Pavement	—	R & H 1540[b]	0	7	—	7	—	—
I-64 Pavement	—	R & H 1540[b]	0.3	39	—	39	—	—
I-64 Pavement	—	R & H 1540[b]	1.0	55	—	47	—	—
I-64 Pavement	—	R & H 1540[c]	Excess	62	—	59	—	—
I-64 Pavement	—	R & H 1540[d]	Excess	61	—	59	—	—
I-64 Pavement	—	None	0	46	—	24	—	—

[a]150 ft^2/gal.
[b]126 ft^2/gal.
[c]58 ft^2/gal.
[d]38 ft^2/gal.

20 to 30 min after the deck was flooded with the HMWM monomers and before gelation of the monomers, the deck was covered with an excess of dry grade A silica sand (±No. 16 sieve size, Table II-19, VDOT *Road and Bridge Specifications*, July 1982) to provide a good skid number. Class I waterproofing (VDOT *Road and Bridge Specifications*, July 1982) was applied to all other areas of the deck. The sections with the HMWM monomers and the Class I waterproofing were opened to traffic at the end of each workday. The results of tests conducted on the overlays in July 1987 and November 1989 are presented in Table 5. The results are based on the average of three tests on each overlay. It can be seen from the data in Table 5 that the HMWM monomer treatment is performing almost as well as the Class I waterproofing (EP5-LV epoxy sand overlay). However, in 1989 the HMWM treatment had all been worn away in the wheel paths, whereas the epoxy overlay was in place. Therefore, epoxy overlays should be used when it is necessary to increase the skid resistance of a bridge deck.

Pavement with Alkali-Silica-Aggregate Reaction

Test sections were placed in June 1986 and August 1987 on the untined westbound travel lane of I-64 in Louisa County near Route 616 and in October 1989 on the tined eastbound and westbound travel lanes of I-64 in New Kent County. Monomer was also applied with a squeeze bottle to individual cracks in June 1986.

The applications placed in June 1986 were removed the following year when the concrete was replaced. Cores taken through the cracks following the treatments indicated that the monomer partially filled the top 1 in. of the cracks.

The 50-ft sections placed in August 1987 were tested for skid resistance in September 1987. The relationship between the skid number and the sand application rate can be seen in Table 4. Sections placed with 0 and 0.3 lb/yd^2 of sand were removed before the opening of the pavement to traffic. Most of the sand placed on the other sections was in place in 1991.

The twenty 100-ft test sections placed in October 1989 are currently under evaluation. Monomers applied to these sections included Revolan RPM-1100-V, Transpo T-70-M, and Sika Pronto 19.

Bridge with Polyester Styrene Concrete Overlay

A multiple-layer polyester concrete overlay was placed on a 33-span bridge on Route 33 in September and October 1988 (*6*). Approximately 1 hr before the placement of the first layer of the overlay on the westbound lane, a primer was placed on each of 6 spans.

The following materials were used in the installation:

- Primer, Span 7: a general purpose, one-component polyurethane primer called Deco-Rez Type I supplied by General Polymers;
- Primer, Span 8: a three-component high-modulus HMWM primer called T-70-P supplied by Transpo Industries;
- Primer, Span 9: a three-component low-modulus HMWM primer called T-70-X supplied by Transpo Industries;
- Primer, Span 10: a three-component low-modulus HMWM primer called RPM-1100-V supplied by Revolan Systems;
- Primer, Span 11: a three-component HMWM high-modulus HMWM primer called RPM-2000 supplied by Revolan Systems (routinely used as a primer for polyester overlays in California);
- Primer, Span 12: a three-component medium-modulus HMWM primer called RPM-2000XT supplied by Revolan Systems;
- Polyester resin: a one-component, general purpose, unsaturated polyester resin called 32-044 supplied by Reichhold Chemical; and
- Aggregate: a No. 8 to No. 20 graded, dry, angular-grained silica sand.

Tensile adhesion tests (ACI 503R) were conducted on each of 9 spans of the bridge: 3 spans with no primer and 6 spans with primer at the ages of 27 days, 1 yr, and 3 yr. The tests showed that the average tensile rupture strength at 27 days, 1 yr, and 3 yr was significantly greater for the spans that received the primer (see Table 6). On the basis of the test results, it is recommended that a primer be used for all multiple-layer polyester concrete overlays. A special provision for a multiple-layer polyester/methacrylate overlay system that consists of a first course of HMWM monomer and two courses of polyester was prepared (*6*).

TABLE 5 Test Results for Untined Bridge

Overlay	Average Tensile Rupture Strength (psi)		Failure at Bond Interface (%)		Permeability of Top 2 in. (C)		Permeability of Base Concrete (C)	
	1987	1989	1987	1989	1987	1989	1987	1989
HMWM	294	453	20	83	1,301	1,529	7,189	5,640
EP5-LV	175	342	63	47	1,087	1,187	—	6,447

TABLE 6 Tensile Rupture Strengths of Bridge Spans with Overlay

Span	Primer	Average Strength (psi)		
		1988	1989	1991
7	Polyurethane	361	355	199
8	T-70-P	351	360	204
9	T-70-X	268	284	242
10	RPM-1100-V	363	181	179
11	RPM-2000	338	298	194
12	RPM-2000-XT	365	307	183
6, 13, 14	None	186	229	103
7–12	All	341	298	200

CONCLUSIONS

1. On the basis of inspections of cores, it is estimated that, on average, the HMWM monomer filled 95 percent of the crack width at the surface. Cracks wider than 0.15 mm were 92 percent filled at a depth of ¾ in., 57 percent filled at a depth of ½ in., and less at greater depths. Cracks 0.15 mm or less in width were 44 percent filled at ¾ in., 35 percent filled at ½ in., and less at greater depths. HMWM monomer was observed at depths up to 2¾ in. and in cracks as narrow as 0.05 mm.

2. The HMWM monomer probably did not penetrate and fill the cracks more completely because of the narrow width of the cracks, less than 0.2 mm on average. Cracks that are wider than 0.2 mm are better candidates for the HMWM monomer treatment.

3. The HMWM monomer treatment did not restore load transfer across the cracks because the monomer only partially filled the cracks and because of the dust, road dirt, and efflorescence on the cracked surfaces. Because of contaminants on the walls of cracks in structures in service, it is unlikely that crack treatments of any type can bond the sides of cracks together.

4. The HMWM monomer treatment reduced the permeability of the cracked and uncracked concrete to chloride ion. The reductions were greater for the longitudinal cracks than for the transverse cracks, particularly after 1 year in service. After 3 years, the protection provided by the T-70-M polymer had decreased, but that provided by the T-70-X polymer had not changed much.

5. Acceptable skid numbers were obtained when the HMWM monomer was applied to a tined texture and when an excess of sand was applied to the HMWM monomer applied on untined surfaces.

6. HMWM monomer can be applied as a prime coat to improve the bond strength of polyester styrene concrete overlays.

RECOMMENDATIONS

1. The application of HMWM monomers such as T-70-X should be considered when it is necessary to reduce the infiltration of chloride ions into cracked concrete surfaces, with cracks having a width of 0.15 mm or more.

2. HMWM monomers should be used as a prime coat to improve the bond strength of polyester styrene overlays.

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