ACKNOWLEDGMENT

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REFERENCES

1. AASHTO Materials, Part I: Specifications, 13th ed. American Association of State Highway and Transportation Officials, Washington, D.C., 1982.
2. AASHTO Materials, Part II: Tests, 13th ed. American Association of State Highway and Transportation Officials, Washington, D.C., 1982.
3. ASTM Standards. American Society for Testing and Materials, Philadelphia, Pa., 1980.
4. Curing of Concrete Pavements. Transportation Research Circular 208. TRB, National Research Council, Washington, D.C., 1970.
5. Briefs of Research Problem Statements Considered by the Special AASHTO Select Committee on Research for the FY 1982 Program of the NCHRP. TRB, National Research Council, Washington, D.C., Sept. 1980.
6. A Chartered Summary of Concrete Highway Pavement Practice in the United States. Portland Cement Association, Skokie, Ill., 1982.
7. Texturing and Skid Resistance of Concrete Pavements and Bridge Decks. FHWA Technical Advisory T5140.10. FHWA, U.S. Department of Transportation, Sept. 18, 1979.
8. Construction and Material Specification. State of Ohio Department of Transportation, Columbus, Jan. 1, 1981.

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Effects of Sawed-Groove Texturing on Concrete Bridge Decks

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ABSTRACT

The experimental application of a sawed-groove texture on two New York bridge decks and one operational use of diamond grinding to rectify an aggravated friction problem on a third deck are discussed. Although tine-texturing has been the chosen concrete deck texturing method in New York, inability to obtain grooves deep enough to provide a long-lasting, high-friction surface has generated interest in trying to saw grooves in new decks. Although used widely for restoring texture on worn concrete pavements, this method had not been generally accepted or promoted for use on new concrete decks. The purpose was to determine if sawing a new concrete deck to produce texture would adversely affect concrete durability and to assess the frictional properties and durability of the texture itself compared with tined surfaces. The determination is based on laboratory tests for chloride permeability and resistance to deicer scaling, and microscopic examinations for microfracturing, as well as field measures of friction and texture depth. Results show that accumulation of chlorides in sawed samples was slightly greater at shallow depths than accumulation in tined textures. At greater depths, no significant difference was found. Tests showed that sawed texturing did not increase the occurrence of scaling, nor cause any small-scale fracturing. Sawed textures were shown to provide a deep and durable frictional riding surface. A disadvantage of sawing is the increased cost compared to tining.

Concrete bridge decks, as well as portland cement concrete pavements, in New York State are finished with a transverse texture produced by a tined metal rake. Although this texturing device has the potential to produce grooves deep enough to provide a long-lasting, high-friction surface on concrete pavements, grooves deep enough to meet the specified minimum depth of 2/16 in. have been hard to attain, particularly on bridge decks on which hand tools are used (1). The problem is aggravated by use of stiffer high-density, low-slump (HDLS) concretes that resist penetration and by latex-modified concretes (LMC) that are too fluid when first placed to hold the grooves. An alternative that has been considered for better assurance of the desired texture depth is to saw grooves after the concrete has cured. Although used widely for restoring texture on worn concrete pavements, this method has not been generally accepted or promoted for new concrete decks. The experimental application of a sawed-groove texture on two New York bridge decks and the operational use of diamond grinding to rectify an aggravated friction problem on a third deck are described.

BACKGROUND

New York State specifications for concrete pavement and bridge deck surface texture have required transverse tining since 1974 (2). Before that, several other finishes had been used. For many years New York textured concrete pavements with a longitudinal burlap drag as did many other states. In the late 1960s, when pavements constructed in New York were found to provide poor friction after the passage of as few as 1 to 2 million vehicles, the first investigations of surface texturing were initiated (3). It was determined that deeper textures were required, and, as a result, transverse bristle-brooming was specified in 1970. A texturing experiment that was begun in 1969 (3) included a heavy burlap drag, a natural-bristle broom, a wire-bristle broom, and a fluted float. Both the burlap and bristle-broom textures were found to wear quickly under traffic, but the fluted-float texture was found to be superior in nearly all respects, and the fluted float was adopted in 1971 as the standard texturing implement (4). This method, first tried on a bridge deck in Utica, was chosen because it provided a deep, high-friction, geometric pattern (1/8-in.-deep ribs on 3/8-in. centers), free of highly abradable peaks or ridges, that was more uniform and durable than that produced by the other methods.

During the 1970 construction season, a small experimental texturing section was placed at Waverly, using a spring-metal tine rake that could be mounted on a normal brooming machine. This new surface proved to have good friction properties and to be highly durable (5,6). Because of positive results at Waverly and problems with adapting the float to mechanical finishing machines, the fluted float was replaced in 1974 by the transverse metal-tine rake (2). The original specifications for tining (7) required use of 3/16-in.-wide, spring-steel tines mounted on 3/4-in. centers capable of producing grooves 3/16 in. ± 1/16 in. deep in plastic concrete. After several years' experience with tining, the department realized that hand-placed tine textures on bridge decks were often shallower than desired on HDLS and LMC overlays, and the requirement for those surfaces was lowered to 1/8 in. ±1/16 in. (8). Given such shallow initial grooves, the ability of such surfaces to sustain adequate drainage and friction over their entire design life has been questioned (1,9).

In an effort to obtain deeper grooves in bridge deck overlays, the department requested in 1979 that the FHWA permit sawing of grooves in hardened HDLS and LMC surfaces (10). Sawed grooves had been shown earlier to provide superior drainage by the National Aeronautics and Space Administration, which stated specifically that ". . . water drainage from runways grooved with the diamond saw technique is greatly increased over ungrooved runway surfaces. It is believed that plastic grooving techniques are not as effective as the sawed groove technique for water drainage because the grooves can be interrupted or misaligned at paving lane edges and the groove channels have rougher wall surfaces" (11,p.96). FHWA denied the request (12), however, on the basis of the assumption that sawing concrete early in its life would cause microfractures that would diminish the durability of the concrete surface, and that the sawed grooves would permit chlorides and moisture to penetrate the concrete at a faster rate than they do tined surfaces. FHWA also believed that friction levels obtained on new overlays were satisfactory, even though the issue of the durability of the friction levels was not addressed.

Research in New York (1,9) has shown that initial grooves 3/16 in. deep should provide adequate friction ($FN_{40} \geq 32$) for the design life (15 years) of most pavements. The department was later encouraged by FHWA to try saw-cutting on an experimental basis, with the proviso that this be compared with tine-texturing in terms of both frictional properties and concrete durability (13,14). As a result, during the 1980 construction season, two bridge deck projects were selected into which sawed textures were incorporated experimentally--one on an HDLS overlay and the other on a conventional concrete full-depth monolithic slab reconstruction (15).

PURPOSE AND SCOPE

A primary purpose of the study reported here was to determine if sawing a new concrete deck to produce texture would adversely affect the durability of the surface. A secondary purpose was to assess the frictional properties, durability, and cost of the sawed texture compared with those of tined surfaces. A third purpose was to record experience with diamond grinding.

The means of making these determinations were (a) laboratory tests for chloride permeability and resistance to deicer scaling, and microscopic examinations for microfracturing, all conducted on 6-in.-diameter cores from the experimental decks, and (b) field measures of friction and texture depth.

The first project involved an HDLS overlay of an existing three-lane, six-span structure on northbound I-87 at Riverbank in Warren County. The first two spans were textured transversely by tining, the third and fourth transversely by sawing, and the fifth and sixth longitudinally by sawing. The second project was a full-depth monolithic reconstruction and widening of two parallel three-span bridges carrying I-88 over NY-369 between Port Crane and Sanitaria Springs in Broome County (referred to here for brevity as "Port Crane"). This project involved reconstruction of both bridge decks, each approximately 165 ft in length, using conventional Class E concrete. One span on each of the two bridges was textured by transverse tining, one by transverse sawing, and one by longitudinal sawing. All sawed grooves on both projects were nominally 3/16 in. ± 1/16 in. deep and 1/10 in. wide on 3/4-in. centers.

A third project was added to the study the following year (1981) when longitudinal diamond grinding was chosen as the method to restore friction to a series of recently constructed decks that had polished and become slippery shortly after being opened to traffic. The specific structure selected for the investigation is a 137.5-ft, three-span bridge carrying I-81 northbound and NY-17 westbound over Chenango Street in Binghamton. It had been resurfaced in 1980 with HDLS concrete but had polished rapidly under exceptionally large volumes of channelized traffic. FHWA permitted this texture restoration method at this site with the condition that its evaluation be included in the research project.

The decision to use a diamond-ground finish instead of sawing grooves to restore friction was based on an examination of macrotexture and microtexture at the site, plus preliminary tests of short sawed and sandblasted sections within the project. From these tests, the problem was determined to be one of microtexture, not macrotexture. Even though the existing tined grooves were shallow, they were judged to be sufficiently deep to provide adequate drainage at the time of testing. Sawing deeper grooves would have helped little because the microtexture (best described as the sandpaper-like roughness of the surface) remained poor and provided little friction. This assessment was confirmed by friction tests that showed little improvement after longitudinal sawing. Obviously, deeper grooves were not the solution. Conversely, the sandblasted surface, which improved microtexture, in combination with the existing tined grooves (macrotexture) provided improvement by 25 friction numbers (FNs) at 40 mph. Although not the case here, grinding has the added benefit of leveling a rutted riding surface.

PROCEDURES AND RESULTS

Monitoring Construction and Texturing

Construction of tined and sawed textures was observed to assess ease of placement and to document any problems encountered. No major problems occurred at the Riverbank project, except the usual one of tining the stiff mix. The typical resultant tine texture is shown in Figure 1. In the author's opinion, the texture depths obtained on this project are about as deep as can be obtained by hand tining on HDLS concrete. Still, initial texture measurements for this bridge were not encouraging; more than 36 percent of the initial groove depths measured were less than the lower specification limit (1/16 in. on HDLS), and more than 99 percent were less than 3/16 in. (Additional information on groove depths will be given later.)

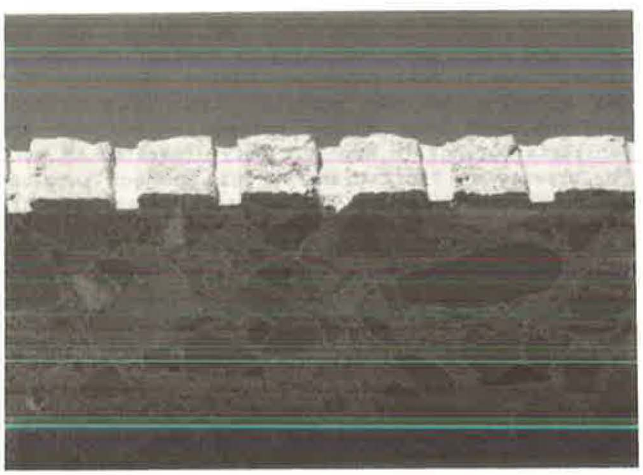


FIGURE 1 Typical tined texture.

Sawing progressed rapidly. Two machines were used, and the only problem was removal of the slurry created from the mixture of cooling water and concrete fragments. Although one machine was equipped with a suction unit to vacuum the slurry from the pavement, it was not totally effective. The smaller saw had no provisions for removing slurry and, in most instances, residue was flushed from the deck with water and allowed to collect in dry wells dug beyond the end of the bridge. Because the project was done by stage construction with the driving lane completed first, tining and sawing were repeated on the passing lane later in the same year. Figure 2 shows a cross section of the sawed texture.

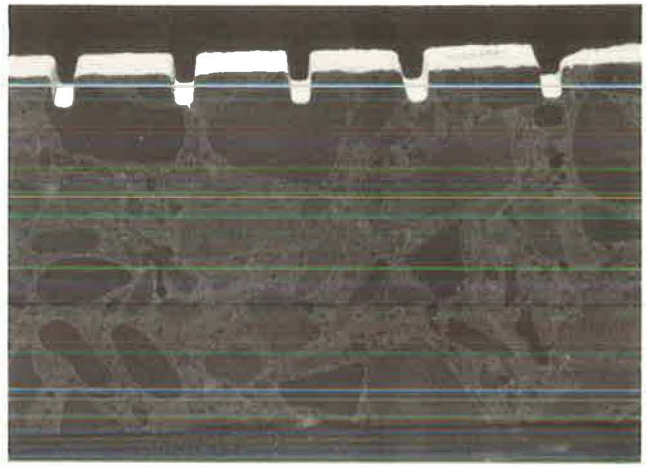


FIGURE 2 Sawed-groove texture.

At Port Crane, concrete placement was plagued with problems. Tining, not attempted in some areas until after the surface had begun to set, resulted in extremely shallow grooves. One tined control section eventually had to be sawed because of severe noncompliance. Sections to be sawed were first bull-floated and then allowed to cure before sawing. Sawing was completed without problem by the same firm and equipment that were used at Riverbank. These two structures were rebuilt full width with all traffic totally detoured.

The three-span bridge at Binghamton was textured with a diamond-grinding machine that provided a longitudinal texture similar in appearance to corduroy (Figure 3). Initially it was intended that a section of transverse grinding also be placed, but this was not possible because of the excessive length of the machine and the need to maintain traffic flow on adjacent lanes during the work. One of the two ground lanes was chosen for testing. A third tine-finished lane was left to be used as a control and to monitor the rapid polishing itself, which had created the original need for grinding. This tined lane had been in place for one winter with the other two, but had carried no traffic because it had been protected by construction barriers.

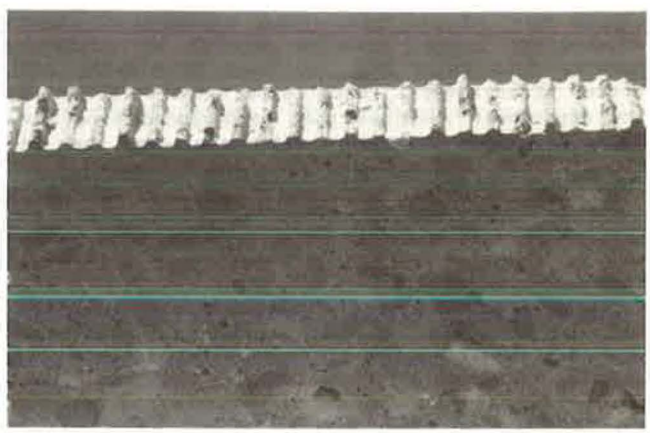


FIGURE 3 Diamond-ground texture.

Field Testing

After the pavement was placed, macrotexture was measured using two methods--sand patch and dial depth gauge. Sand-patch tests (16,17) were made in the left wheelpath of each test lane. Individual tests were made at 10 random locations within each test site, defined as the traveled lane of one span for each texture type, from which a mean texture depth (MTD) was calculated. Individual test locations were carefully identified to permit returning to the same location on subsequent visits.

Groove depths were measured with a dial depth gauge (Figure 4) previously used in New York on grooved surfaces (1,18,19). On transverse textures, grooves were measured at close intervals along the entire length of the left wheelpath of each test site, and mean groove depths (MGDs) were calculated. On longitudinal textures, grooves were measured over a 1-ft distance perpendicular to the centerline of the wheelpath at each sand-patch test location. Initial MGDs were used to assess compliance with the texture depth specified and will be discussed later.

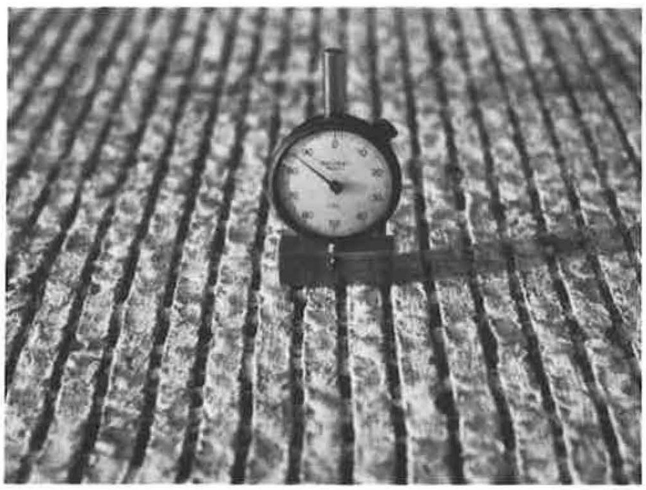


FIGURE 4 Measuring groove depth with a dial gauge.

Microtexture was measured with a British Portable Tester (ASTM E 303-74) only at the Binghamton project. This method was chosen because it is a good indicator of the effect of surface polishing (change in microtexture), which has been the major problem on this project. The British Portable measurements (BPNs) were made at the same test locations as sand-patch measurements.

All texture measurements were repeated annually to determine texture loss with traffic. Measurements at Binghamton were collected semiannually because of the unusually high traffic levels (43,900 annual average daily traffic).

Friction quality was tested in the left wheelpath of each test lane according to ASTM E 274-77 at both 40 and 55 mph. All tests employed a standard ribbed test tire (ASTM E 501-76) and, when possible, a smooth test tire (ASTM E 524-76).

After texturing had been completed, forty 6-in.-diameter cores were taken from random locations on each of the first two projects for laboratory tests for chloride penetration and resistance to deicer scaling and for microscopic inspection. Thirty-two cores were extracted from random locations on the diamond-ground deck for chloride penetration analysis and microscopic inspection. Tests for resistance to deicer scaling could not be completed on cores from ground surfaces because the rating system is based on the rate and amount of coarse aggregate exposed, and grinding exposes the coarse aggregate.

Laboratory Testing

Cores representing textures sampled at the different sites were separated into groups for testing, the number in each group corresponding to that which would provide a total surface area sufficient to meet the requirements of the particular test. A summary of the results is given in Table 1.

Chloride permeability was measured using a method described by Clear and Chollar (20) in which a 3 percent NaCl solution is ponded on the core surface for 90 days and the concrete is then sampled and analyzed for chloride content. Core surfaces were first cleaned of residual curing compound and other contaminants by wire brushing or light sandblasting. Cores were selected for determining both baseline chlorides and chlorides after the 90-day ponding period. Powder samples for chloride analysis were collected by drilling a 1-in.-diameter vertical hole in 1/2-in.-deep increments from the core surface to a total depth of 3 in. At each increment, the powder was collected and analyzed by atomic absorption.

For the ponding tests, dams consisting of 1-in.-high rings of 4-in.-diameter polyvinyl chloride (PVC) pipe were cemented to the core surfaces (Figure 5). The dams were filled with the 3 percent NaCl solution and maintained at a depth of 1/2 in. for the full 90 days, during which the rings were covered with glass plates to reduce evaporation. After 90 days, samples for chloride analysis were removed and tested as previously described. In reporting the results (Table 1), the zero depth level was taken as the bottom of the texture grooves.

It is again noted that the Binghamton deck on which the new texture was ground had experienced one winter season of traffic before grinding. Baseline chloride contents at that site thus were measured in cores from a 1-year-old tine-textured surface. The lane that was not ground and remained as a tine-textured surface had also been in place one winter, but was untraveled due to the arrangement of traffic barriers. Baseline chloride levels in cores from that location resulted from overspray and splashing rather than direct application.

The test for resistance to deicer scaling followed ASTM C 672-76, except for changes required to adapt it to core samples and the use of a 3 percent rather than a 4 percent NaCl solution. PVC dams were also cemented to these cores and the NaCl solution maintained at a depth of 1/4 in. Ponded cores were placed in a freezer for 16 to 18 hr, which lowered the temperature to about -2°F by the end of the cooling period. The cores were then removed and allowed to thaw in laboratory air for 6 to 8 hr at 73°F ± 3°F and a nominal relative humidity of 35 to 50 percent. This cycle was repeated daily for 90 days. These temperatures were consistently met, but laboratory humidity occasionally deviated from this range. At the end of each five cycles, the cores were flushed with distilled water and rated, based on the following rating scale:

0 = no scaling;
1 = very slight scaling (1/8-in. depth maximum, no coarse aggregate visible);
2 = slight to moderate scaling;
3 = moderate scaling (some coarse aggregate visible);
4 = moderate to severe scaling; and

TABLE 1 Summary of Laboratory Testing and Results

Concrete	Texture	Condition	Treatment	Mean Cl^- Concentration, ppm 0–.5 in.	Mean Cl^- Concentration, ppm .5–1 in.	n[e]	Scaling Mean Rating[f]	Scaling n	Microscopic Exam, n
RIVERBANK (I 87)									
HDLS	Tined[a]	Baseline	1 winter	1446	195	3	-	-	-
	Sawcut[b]	Baseline	1 winter	1723	354	5	-	-	-
	Tined	+ Cl^- pond	1 winter + 90-day pond	1875	215	8	1.4	6	-
	Sawcut	+ Cl^- pond	1 winter + 90-day pond	2044	193	8	1.0	6	-
PORT CRANE (I 88)									
Class E	Tined	Baseline	None	0	0	4	-	-	-
	Sawcut	Baseline	None	20	0	2	-	-	-
	Tined	+ Cl^- pond	90-day pond	1582	858	6	2.0	8	1
	Sawcut	+ Cl^- pond	90-day pond	1923	927	6	2.1	8	3
BINGHAMTON (I 81 & Rte 17)									
HDLS	Tined	Baseline	1 winter	1462	519	3	-	-	-
	Ground[c]	Baseline	1 winter	1840[c]	444	3	-	-	-
	Tined	+ Cl^- pond	1 winter + 90-day pond	1661[d]	205	8	2.2	6	-
	Ground	+ Cl^- pond	1 winter + 90-day pond	2061[d]	293	8	-	-	1

[a]All tining was in the transverse direction.
[b]For lab testing, longitudinal and transverse sawcuts were considered the same.
[c]Samples actually experienced one winter in place tine-textured; the lane was ground the following summer, then tested.
[d]Net Cl^- content increase after 90-day soak is similar for both textures.
[e]n = number of cores tested.
[f]By ASTM C 672, scale of 1 to 5, increasing as condition diminishes.

FIGURE 5 Chloride solution ponded on core surface.

5 = severe scaling (coarse aggregate visible over entire surface).

Fifty cycles are suggested as sufficient for a valid test, but, because of the low scaling rates experienced, all cores were continued through 90 cycles. Final scaling ratings are given in Table 1.

Sawed and tined surfaces of cores from the first two projects were examined microscopically in finely ground sections to determine if the texturing had caused any small-scale fracturing of the concrete. No damage or alteration caused by sawing was found.

DISCUSSION

Construction and Texture Compliance

This study was initiated because sufficiently deep grooves were not being obtained on bridge deck overlays. Grady and Chamberlin (1,p.75) had noted that ". . . mean groove depths of 2/16 in. and 3/16 in. are attainable with proper attention to equipment, technique, and particularly timing of the texturing process." Although this statement still applies for pavements placed with conventional portland cement concrete, it does not necessarily hold for the special overlay materials now being used in bridge deck rehabilitations, for the reasons cited earlier. Table 2 gives a summary of the initial tined groove-depth measurements on the three projects as well as the initial sawed data. The lack of tining compliance in these projects with even a 2/16-in. standard (i.e., 91.9 and 100.0 percent, respectively) is discouraging. As suggested earlier (1), it appears that HDLS concrete cannot be tined consistently to either depth.

Grady and Chamberlin (1) noted that 56 percent of individual groove-depth measurements on 20 tined, conventional Class E concrete decks were less than the 2/16-in. minimum required, and less than 14 percent were 3/16 in. deep or more. At Port Crane, where Class E concrete was used, 69.6 percent of the measurements were less than 2/16 in., and only 2.1 percent were greater than 3/16 in. For whatever reason, tining is not producing the texture depth sought on conventional concrete decks either.

Sawing can be set for any reasonable depth, but it is to the operator's benefit to cut near the specified lower limit in order to minimize blade and machine wear and to maximize the production rate. The minimum depth required on these projects was 2/16 in., and only 14.8 percent of the individual MGDs measured were less than 2/16 in. The average value within every lane of each span, however, was well above this minimum.

TABLE 2 Initial Groove-Depth Measurements

Concrete	Texture	Groove Depth Specified, in.	MGD, in.	%< 1/16 in.	%< 2/16 in.	%> 3/16 in.
RIVERBANK						
HDLS	Tined	2/16 ± 1/16	0.077	36.7	91.9	99.7
	Trans. Sawed	3/16 ± 1/16	0.141	0.2	29.1	96.2
	Long. Sawed	3/16 ± 1/16	0.183	0.0	3.1	52.5
PORT CRANE						
Class E	Tined	3/16 ± 1/16	0.103	19.4	69.6	97.9
	Trans. Sawed	3/16 ± 1/16	0.145	0.0	29.1	92.7
	Long. Sawed	3/16 ± 1/16	0.169	0.0	6.6	71.0
BINGHAMTON						
HDLS	Tined	2/16 ± 1/16	0.049	80.5	100.0	100.0

The only problem encountered of any consequence was removal of slurry, as noted before. All machines should be equipped to be capable of effectively removing such slurry from the pavement surface. The grinding machines at Binghamton had effective vacuum removal systems that certainly could be installed on sawing machines. Otherwise, sawing is an effective and rapid method of applying macrotexture to concrete surfaces.

The microtexture of the "lands" area between the grooves is also important. As shown at Binghamton and noted previously here, deep grooves cut into a surface with a poor microtexture may not provide good friction. Initial roughness, or macrotexture, could be obtained by using one of several plastic-concrete texturing devices, such as an astroturf drag. This surface, in combination with sawed grooves for macrotexture, would appear to provide excellent frictional properties at least until the macrotexture polishes.

Grinding at Binghamton was quick and simple and resulted in a neat, uniform surface texture with both good macrotexture and good microtexture. The initial peaks break off immediately under traffic and leave a well-defined washboard pattern cut into the coarse aggregate. Although the installation was longitudinal here, transverse installations should also be acceptable.

Chloride Permeability

Data on chloride permeability of 6-in.-diameter cores removed from the experimental pavements are summarized in Figure 6. No distinction has been made between transverse and longitudinal sawing, because the direction of cutting would have had no effect on the results of such laboratory tests.

Results from all three sites (Figure 6 and Table 1) indicate the accumulation of chlorides from both sawed and ground surfaces to be greater than that from tined surfaces at shallow depths (0 to 1/2 in.). These differences are small and probably not statistically significant for the number of samples

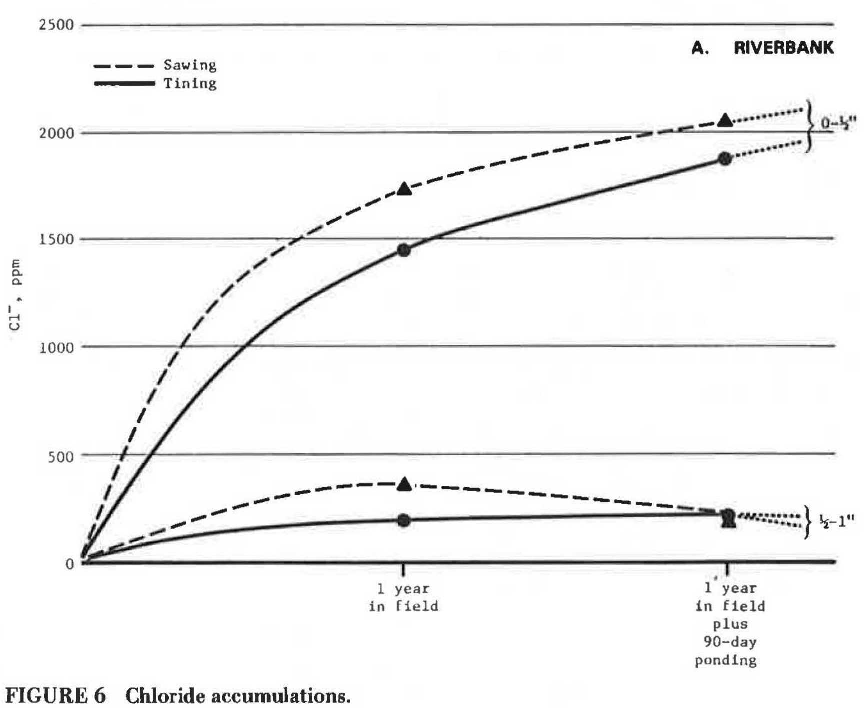
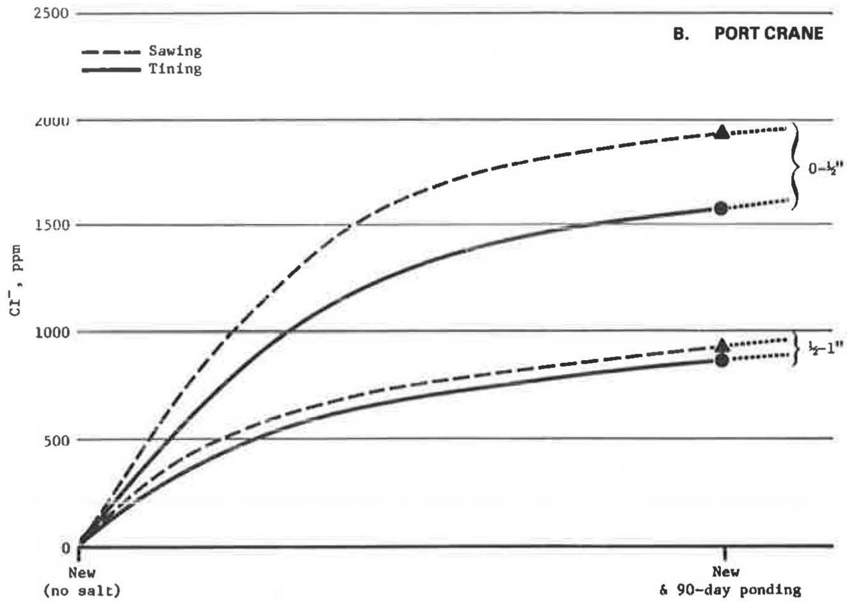


FIGURE 6 Chloride accumulations.



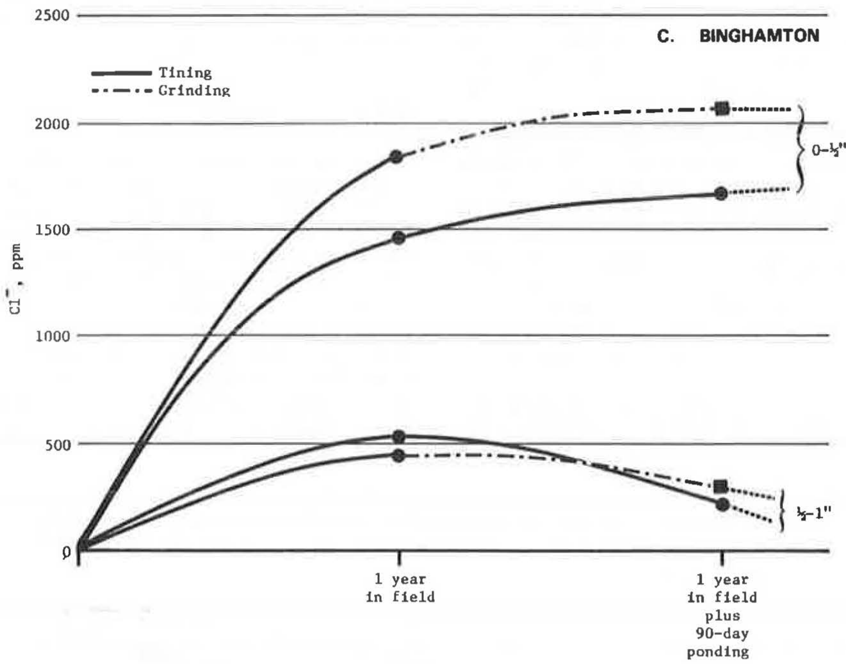


FIGURE 6 (continued)

tested, but they are consistent among the three projects. From the Riverbank and Binghamton projects (Figure 6), where the surfaces were exposed through one full winter before coring, it would appear that, after some differentiation during initial accumulation, the rates of accumulation are roughly equivalent.

At the 1/2- to 1-in. level, chloride accumulations in the ponding test were by comparison smaller than those at the 0- to 1/2-in. level, as were the apparent differences between texturing methods. These latter differences were not consistent among the three sites at the same sampling time, nor within the same site at different sampling times.

Resistance to Deicer Scaling

Results of the scaling tests are given in Table 1 as the average final rating (on a scale of 1 to 5) of a group of cores from each of the two texture types--tined and sawed. Although the test procedure specifies 50 cycles of freezing and thawing, the tests were extended to 90 cycles because of a lack of differentiation after 50 cycles. Even after 90 cycles, results show little difference between sawed and tined surfaces, with no single sample scaling beyond a rating of 3. Sawed texturing did not appear to increase the occurrence of scaling.

Decay of Texture

All textures on highway surfaces decay under traffic. The goal of highway engineers is to achieve a texture that is sufficiently deep initially and has a low enough decay rate to result in safe, high-friction surfaces that endure for the life of the pavement. For long-term durability of a surface to be studied, large numbers of vehicles must pass over it. Because none of the surfaces described here has yet experienced a significant amount of traffic, long-term durability could not be estimated. However, some interesting short-term trends are noted.

In Table 3, the average loss in texture depth per million vehicle passes (MVP) is given for each experimental location. As expected, the ground texture shows the highest decay rate, most likely attributable to the small tire contact area that consists initially of the slender peaks between the grooves. Wear rate of this surface would be expected to be greatest at the outset and then to decline with increasing traffic as tire contact area increases. Collection and analysis of further data should define the nature of this decay more precisely.

TABLE 3 Change in Texture Depth with Traffic

Location	Concrete	Texture	ΔMTD per MVP	ΔMGD* per MVP
Riverbank	HDLS	Tined	0.010	0.006
Port Crane	Class E	Tined	0.014	0.015
Binghamton	HDLS	Tined	0.000	0.005
Riverbank	HDLS	Trans. Saw	0.004	0.006
Port Crane	Class E	Trans. Saw	0.002	0.007
Riverbank	HDLS	Long. Saw	0.004	0.000
Port Crane	Class E	Long. Saw	0.002	0.003
Binghamton	HDLS	Ground	0.021	0.023

*Some individual sites may show very slight increases in MGD, due to variable groove depths over the span measured, and very slow decay, and are considered as ΔMGD = 0.

Tined surfaces as a group have experienced the next highest decay rate, although there are striking differences within the group. The higher rate of decay at Port Crane is probably related to the use of Class E concrete, which because of its higher water-cement ratio would have less abrasion resistance than the HDLS concrete used on the other two projects. Also, because the Class E concrete generates more mortar at its surface during finishing, the tining rake can penetrate deeper, and the mortar so displaced contributes to a fine-textured roughness between the grooves that abrades more rapidly than when the grooves are shallower. Abrasion of this type of texture is reflected in measurements by both the sand-patch test and the groove-depth gauge. The lower decay rates measured in tined surfaces at Riverbank and Binghamton undoubtedly reflect use of the stiffer, more abrasion-resistant HDLS concrete. The tined surface at Binghamton was virtually free of microtexture from the outset.

Early texture decay rates measured on sawed surfaces at both Riverbank and Port Crane are generally lower than those associated with either of the other two methods but comparable to the tined site at Binghamton where texture development between grooves was poor. Sites chosen for sawing were first floated smooth, then sawed and, as a result, have little texture between the sawed grooves. Low early decay rates, measured by both MTD and MGD, were found.

To generalize, it appears that the rate at which grooved textures decay early in their life, at least as measured by the methods used here, will depend on at least two factors: (a) the level to which small-scale texture has been developed between the grooves (whether tined or sawed) and (b) the abrasion resistance of the concrete itself. Thus, high early decay rates that result from abrasion of this small-scale texture should not necessarily be considered undesirable. They may instead be an unavoidable by-product of a well-developed intergroove roughness that most engineers consider desirable.

Decay of Friction

Results of friction tests (Table 4) are available for only 2 years because of a friction trailer breakdown in 1980. Also, no friction tests were made at Port Crane because of the inadequate length of the experimental spans, an unanticipated problem that resulted from undampable disturbances introduced by the armored joints at the beginning of each new span. As with texture decay, long-term friction-decay rates cannot be estimated because of the relatively low volume of traffic to this date. At Riverbank (Figure 7), the tined textures provided the highest friction with a standard deep-ribbed test tire at all levels of traffic at both 40 and 55 mph. The combination of small-scale pavement roughness, consisting of small peaks and ridges of mortar displaced by the tine rake, and the superior drainage afforded by the tire's grooves yielded the highest friction numbers.

Initial friction measurements on sawed surfaces could be elevated to the level of those of tined surfaces by dragging the plastic concrete with astroturf or by brooming to provide roughness between the grooves. This would be a particular benefit if traffic were required to use the surface before it was sawed. In all tests in which the smooth tire was used, transverse sawcut texture resulted in the

TABLE 4 Friction Levels

		Ribbed Tire				Smooth Tire			
		1981		1982		1981		1982	
Texture	Location*	FN_{40}	FN_{55}	FN_{40}	FN_{55}	FN_{40}	FN_{55}	FN_{40}	FN_{55}
Tined	Riverbank DL	36.1	36.4	35.4	31.9	29.5	N.A.	28.8	24.3
Tined	Riverbank PL	55.7	45.2	45.6	39.7	36.9	"	34.6	26.7
Tined	Binghamton	29.7	30.2	30.6	28.3	N.A.	"	19.6	21.2
Trans. saw	Riverbank DL	35.3	32.2	33.1	30.1	32.9	"	33.3	27.8
Trans. saw	Riverbank PL	50.5	42.8	45.5	39.2	43.1	"	41.9	35.8
Long. saw	Riverbank DL	33.6	29.4	32.5	29.3	29.3	"	31.5	26.1
Long. saw	Riverbank PL	49.8	42.2	44.7	37.9	40.5	"	40.8	33.2
Ground	Binghamton	45.5	37.3	51.2	47.9	N.A.	"	48.1	39.9

*DL = driving lane, PL = passing lane; HDLS concrete at both locations.

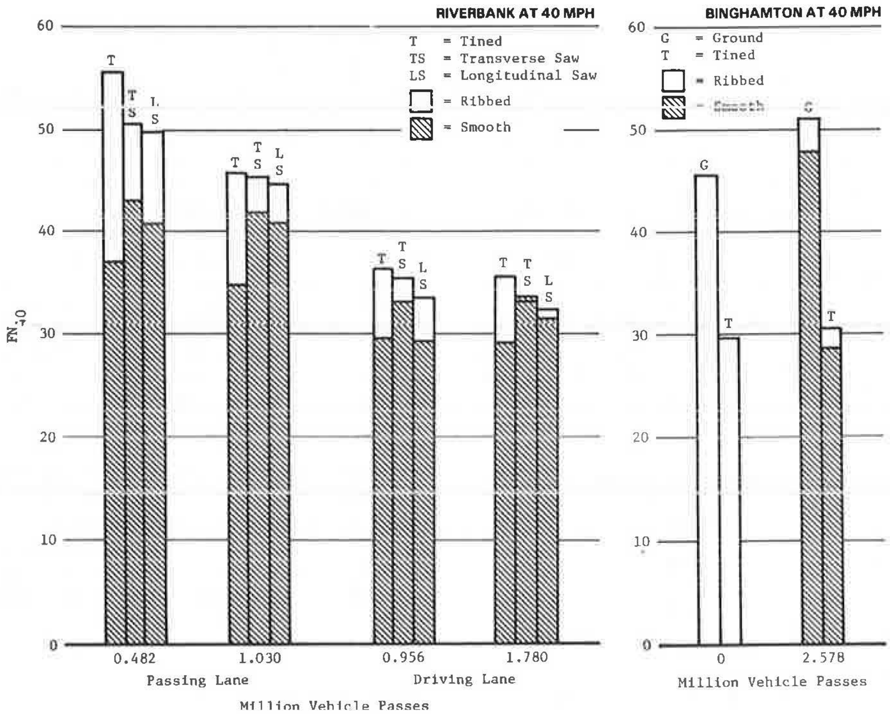


FIGURE 7 Friction levels.

highest friction, followed by longitudinal sawcut texture and tined texture, in that order (Figure 7). This is explained by the smooth tire being entirely dependent on the pavement for drainage, which the sawed textures are more capable of providing because of their greater depth. Normal car tires have ribs (minimum 2/32 in. in New York) that are much shallower than the ribs of the ASTM test tire and thus depend on pavement texture for much of their drainage. Although both the tined and sawed grooves will wear, sawed grooves start out deeper, remain deeper, and thus provide the required drainage longer.

At Binghamton (Figure 7), the ground texture resulted in good friction with both ribbed and smooth tires. It satisfied needs for both macrotexture and microtexture. The tined section, left as both a control and an object of study itself (as noted earlier), yielded a lower FN and declining BPNs, an indicator of declining microtexture. Additional traffic wear should magnify this problem.

Cost Comparison

The cost of sawing varied from $1.00 per square foot to $1.50 per square foot. At Riverbank, itemized bid prices were $1.50 per square foot longitudinally and $1.40 per square foot transversely. Both textures were bid at $1.00 per square foot at Port Crane. The cost for tining was not directly recoverable because it is included in the unit price for deck placement. However, it is low in comparison and consists of the labor cost of one mason during a portion of the deck placement period. Grinding costs were $1.00 per square foot including traffic control and were included as a change order in the contract.

The cost of sawing should decline as its use increases. A major expense for these two projects was mobilization; the equipment and personnel came from Tennessee to complete rather small jobs. The grinding-grooving subcontractor expressed the opinion that future prices might be in the range of $0.25 to $0.45 per square foot exclusive of any union fees.

Summation

The results discussed in this paper should encourage the use of sawed grooves in those situations in which tining does not provide an adequate texture--a condition that occurs on bridge decks, especially those with HDLS or LMC overlays. An added benefit associated with sawing is improved curing. The need for hand surface finishing is reduced, and curing blankets can be placed immediately. Curing blankets cannot be placed on freshly tined surfaces because they flatten the texture, and membrane curing compounds are not applied until after the surface is tined. A disadvantage is increased cost.

CONCLUSIONS

Tined grooves 2/16 in. or more deep were achieved on the two HDLS bridge decks only 10 percent of the time or less. On the one conventional Class E concrete deck, 30.4 percent of the grooves were 2/16 in. or deeper.

Accumulation of chloride from sawed and ground surfaces in 90-day ponding tests was higher within 1/2 in. of the bottom of grooves than under tined surfaces. The differences were consistent among the three projects studied, but the differences were small and not considered significant in view of the variability of the chloride analysis procedure. At 1/2 in. or deeper, there was no difference.

Sawed and tined surfaces did not differ in their resistance to deicer scaling in accelerated laboratory tests (ASTM C 672-76).

Microscopic examination of finely ground cross sections of cores showed no evidence of small-scale fracturing or other damage to concrete caused by mechanical texturing.

Initial losses of texture depth, measured by the sand-patch test and by dial depth gauge were greatest for ground surfaces, followed by tined grooves in conventional Class E concrete. Tined grooves in HDLS concrete and sawed grooves were variable, but they were at a generally lower level than either of the others.

All methods of texturing produced acceptable initial values of friction when tested with a standard ribbed tire. Those produced by grinding and tining were higher in general than those produced by sawing. When tested with a smooth tire, ground and sawed textures were superior.

Bid prices for sawing grooves 3/16 in. ± 1/16 in. deep on 3/4-in. centers varied from $1.00 per square foot to $1.50 per square foot. The bid price for grinding, which is not directly comparable because it included traffic control and extended over a much greater area, was $1.00 per square foot.

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REFERENCES

1. J.E. Grady and W.P. Chamberlin. Groove-Depth Requirements for Tine-Textured Pavements. In Transportation Research Record 836, TRB, National Research Council, Washington, D.C., 1981, pp. 67-76.
2. New Texturing Method for Portland Cement Concrete Pavement. Engineering Instruction 74-22. New York State Department of Transportation, Albany, Feb. 21, 1974.
3. W.P. Chamberlin and D.E. Amsler. Pilot Field Study of Concrete Pavement Texturing Methods. In Highway Research Record 389, HRB, National Research Council, Washington, D.C., 1972, pp. 5-17.
4. Texturing Portland Cement Concrete Paving. Instruction 71-23. Facilities Design Division, New York State Department of Transportation, Albany, July 23, 1971.
5. W.P. Chamberlin and W.G. Leslie. Concrete Pavement Texturing Methods: A Review of New York's Experience. Research Report 70. Engineering Research and Development Bureau, New York State Department of Transportation, Albany, April 1979.
6. G.K. Ray and L.T. Norling. More Macrotexture in Concrete Pavement for Greater, Longer Lasting Skid Resistance. Presented at 53rd Annual Meeting of the Transportation Research Board, Washington, D.C., 1974.
7. New York State Department of Transportation. Standard Specifications, Albany, Jan. 2, 1981. Item 502-3.09, Finishing and Texturing, pp. 5-21 and 5-22; Item 555-3.08, Finishing, pp. 5-55 through 5.54.
8. Placing and Finishing Overlay. Item 584-3.09, Addendum No. 1. to Standard Specifications of Jan. 2, 1981. New York State Department of Transportation, Albany, Dec. 9, 1982, pp. 53-55.
9. J.E. Grady. Decay of Tine-Textured Grooves in Rigid Pavements. Research Report 107, Engineering Research and Development Bureau, New York State Department of Transportation, Albany, Oct. 1983.
10. Texturing of Concrete Bridge Decks. Memorandum from J. Sternbach, Director, Construction Division, New York State Department of Transportation, Albany, to V.E. Taylor, Division Administrator, FHWA, U.S. Department of Transportation, Nov. 30, 1977.
11. W.B. Horne. Status of Runway Slipperiness Research. In Transportation Research Record 624, TRB, National Research Council, Washington, D.C., 1976, pp. 95-105.
12. Texturing of Concrete Bridge Decks. Memorandum from V.E. Taylor, Division Administrator, FHWA, U.S. Department of Transportation, to J. Sternbach, Director, Construction Division, New York State Department of Transportation, Albany, Jan. 26, 1978.
13. Texturing of Concrete Bridge Decks. Memorandum from V.E. Taylor, Division Administrator, FHWA, U.S. Department of Transportation, to J. Sternbach, Director, Construction Division, New York State Department of Transportation, Albany, Dec. 13, 1977.
14. Texturing of Concrete Bridge Deck Overlays. Memorandum from V.E. Taylor, Division Administrator, FHWA, U.S. Department of Transportation, to J. Sternbach, Director, Construction Division, New York State Department of Transportation, Albany, May 4, 1978.
15. Project Work Plan Transmittal Letter from W.P. Hofmann, Deputy Chief Engineer, New York State Department of Transportation, Albany, to V.E. Taylor, Division Administrator, FHWA, U.S. Department of Transportation, March 8, 1979.
16. Guideline for Texturing of Portland Cement Concrete Highway Pavements. Technical Bulletin 19. American Concrete Paving Association, Arlington Heights, Ill., March 1975.
17. D.E. Amsler and W.P. Chamberlin. Measuring Surface Textures of Concrete Pavements by the Sand-Patch Method. Research Report 62. Engineering Research and Development Bureau, New York State Department of Transportation, Albany, July 1978.
18. E.D. McNaught. Demonstration of a Flail-Type Pavement Grooving Machine. Special Report 53. Engineering Research and Development Bureau, New York State Department of Transportation, Albany, Feb. 1977.
19. G.F. Gurney and J.E. Bryden. Effectiveness of Transverse Grooves in Rigid Pavement. Research Report 99. Engineering Research and Development Bureau, New York State Department of Transportation, Albany, Oct. 1982.
20. K.C. Clear and B.H. Chollar. Styrene-Butadlene Latex Modifiers for Bridge Deck Overlay Concrete. Report FHWA-RD-78-35. Office of Research and Development, FHWA, U.S. Department of Transportation, April 1978.

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