Sprinkle Treatment of Asphalt Pavements

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In an effort to promote and accelerate the widespread adoption and use of practical highway research results and improve communication by demonstrating the results, the Federal Highway Administration (FHWA) established the Demonstration Projects Program in 1969. Since its inception, more than 60 projects have been approved. One currently active project, a demonstration project on sprinkle treatment of asphalt pavements, was announced in November 1977. Fourteen participating agencies have constructed 25 separate demonstration installations in connection with this project, and one more is planned for later this year. A comparative summary of these projects is presented that includes the history and background of sprinkle treatment, design considerations and construction guidelines, economic considerations, and specific construction and performance data for each project. Information from sprinkle treatment projects and corresponding control sections is tabulated and analyzed. Recommendations are made based on the experience gained from these projects. The subject areas discussed include the following: aggregate types, aggregate gradations, coating rates and asphalt cements used for precoating, construction controls, equipment requirements, weather conditions during construction, placement problems and solutions, construction costs, sprinkle aggregate retention, and skid performance with texture measurement and speed gradients. From the performance data gathered to date on the various demonstration installations, it can be concluded that sprinkle treatment is a viable alternative construction method for obtaining improved skid resistance characteristics on asphalt pavement surfaces of low-volume roadways, especially in areas where polish-resistant aggregates are not locally available or are expensive.

Current demands for highway safety are coming at a time when available construction funds are dwindling and natural resources are rapidly being depleted. One area of concern is the increase in wet-pavement accidents, which have caused the loss of many lives, millions of dollars in medical care, and billions of dollars in property damage. Everyone involved with the planning, development, and construction of highways can contribute to reducing this problem by striving to provide pavement surfaces with good skid-resistance characteristics. To accomplish this, it may be necessary to develop innovative alternatives to traditional construction techniques.

Research has determined that the macrotexture of pavement surfaces and the microtexture of aggregates used in paving mixes are the primary factors that contribute to the skid resistance of a pavement surface. It has been shown that these textures, particularly the microtexture, smooth out or polish under traffic over a period of time. This polishing effect reduces the friction at the tire-pavement interface, which increases the potential for wet-pavement accidents. There are, however, certain types of aggregates that polish at a much slower rate under traffic. One may conclude, therefore, that the most effective way to reduce wet-pavement accidents is to use these polish-resistant or quality aggregates in all pavement surface mixes. Unfortunately, this is not always possible because the cost and availability of quality aggregates are often prohibitive factors. In some states, quality aggregates must be shipped many miles, which significantly increases the cost of surface course mixes. As a result, additional efforts have been made in recent years to develop alternative methods that use less quality aggregate in pavement surface mixes.

One such alternative currently being promoted by the Demonstration Projects Division of FHWA is sprinkle treatment of asphalt surfaces. This technique allows the use of locally available, polish-susceptible aggregate throughout a hot-mix pavement while requiring only a minimum amount of polish-resistant, precoated aggregate on the surface. The precoated sprinkle aggregate is applied to the surface of a freshly placed, hot-mix mat and then embedded in the surface during the rolling operation. The use of the quality aggregate on the pavement surface provides for good skid-resistance characteristics while eliminating the need for more expensive quality aggregate throughout the remainder of the surface course (see Figure 1). This technique conserves supplies of quality aggregate and reduces the cost of constructing skid-resistant pavements in areas where quality aggregates are not readily available. Additional benefits include increased macrotexture, which reduces the possibility of hydroplaning through improved surface drainage and better contact between the tire and the quality-aggregate surface. Figure 2 shows a sprinkle treatment section adjacent to a conventional section after 1 year of service. Note the improved surface texture and exposed quality aggregate of the sprinkle treatment section.

HISTORY AND BACKGROUND

Sprinkle treatment has been used extensively for more than 20 years in Europe, where polish-resistant aggregates are extremely scarce (1,2). Initially, several approaches were used to prepare the sprinkle chips, including hot and cold precoated aggregate

Figure 1. Material with quality aggregate throughout versus sprinkle treatment material.

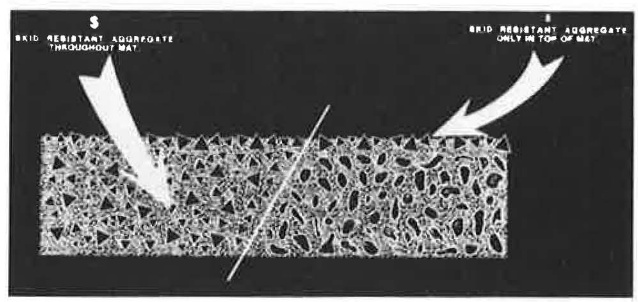


Figure 2. Sprinkle treatment section (left) adjacent to conventional dense-graded section after about 1 year of service.

and hot noncoated aggregate. The hot precoated aggregate often caked, however, which made it difficult or impossible to spread. The hot noncoated aggregate was difficult to keep hot for long periods, and as it cooled it failed to adhere to the paving mix. Ultimately, hot precoated aggregate that was then allowed to cool became the most widely used method of preparing the sprinkle chips (2-4).

In the United States, the Virginia Department of Highways and Transportation (VDHT) was the first highway agency to try sprinkle-mix construction techniques. In 1968-1969, the VDHT placed its first experimental test sections and by 1977 had placed more than 200 miles of sprinkle-treated pavements (5). The Texas State Department of Highways and Public Transportation (TSDHPT) placed its first sprinkle-mix test sections in 1972 and has subsequently placed several hundred additional miles. The Iowa Department of Transportation (DOT) has been using this technique for several years and has placed more than 425 miles of sprinkle-treated pavements.

A critical part of the sprinkle treatment operation is the manner in which the precoated aggregates are spread. Initially, aggregates were spread by using various existing chip spreaders that were not specifically designed for use with precoated aggregates. Among the early spreaders were the "whirly-bird" salt spreaders (see Figure 3) attached to the back of a dump truck, which were used to apply precoated aggregate in the early 1970s, and conventional chip spreaders (see Figure 4), which were allowed to travel on the freshly placed hot-mix mat behind the paver. With the whirly-bird, application rates were not uniform, quality aggregate was wasted in the opposing lane and shoulder, and tire marks were left on the mat. The chip spreader was difficult to charge, required additional labor to keep precoated aggregate flowing, and also left tire marks on the mat. Because both types left tire marks in the pavement surface that could not be rolled out, they are not recommended.

Several significant factors were recognized in these early sprinkle treatment projects:

1. An effective spreader had to be capable of spanning the entire mat in order to eliminate tire marks.
2. An efficient means of charging the spreader with precoated chips had to be considered.
3. Some type of stirring mechanism was needed to keep the precoated aggregate free flowing.
4. The spreader had to be capable of maintaining positive control of the aggregate distribution.

These factors were all kept in mind during the fabrication of second-generation machines by the VDHT and the TSDHPT. Although these homemade machines addressed the problems of tire marks and uniform distribution, there were still several problems associated with their use. The VDHT spreader (see Figure 5), constructed from old truck parts, was the first spreader that could span the new 12-ft-wide mat. But it required release agents to prevent sticking problems, allowed a large section of mat to cool before compaction, contaminated the mat with roadside debris during the charging operation, and required more labor and handling. The TSDHPT spreader (see Figure 6), constructed from an old spreader box, was set up with a hitch for towing behind the paver and a chute for charging. The TSDHPT spreader had a uniform spread rate and created no compaction or embedment problems, but it was still difficult to charge and required additional labor and handling.

Since 1978, several projects have been constructed by using the Bristowes MK V hydrostatic, self-propelled chip spreader. Imported from Great Britain, the Bristowes spreader is currently the only commercial, self-propelled spreader available in the United States. It lends itself well to projects in any location because it is portable and can be hauled on a trailer by any common carrier. When the spreader arrives at the project site, it can be quickly unloaded and incorporated into a paving train. It is designed specifically to spread cool, precoated aggregate (nominal size of 0.5 in. with less than 5 percent passing the No. 4 sieve) while spanning a freshly placed hot-mix surface course (see Figure 7) (1,6-8). As the use of sprinkle treatment becomes more widespread, it is likely that equipment manufacturers in the United States will develop and build chip spreaders comparable to the Bristowes machine.

One of the advantages of the Bristowes spreader is that it is simple to operate. Two separate controls are used to drive the left and right wheels of the spreader independently in either direction. A traversing hopper fills the lower storage bin, where gates and fluted drums control the rate of distribution. A third control handle is used to move the traversing aggregate hopper for charging the spread-

Figure 3. Twin whirly-bird salt spreaders used to apply precoated aggregate in early 1970s.

Figure 4. Conventional chip spreader.

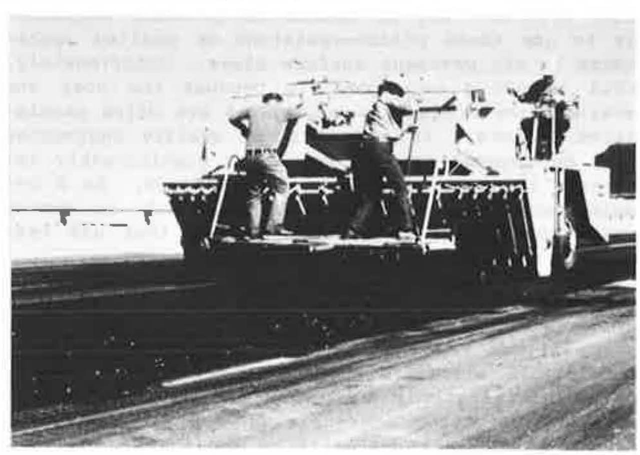


Figure 5. VDHT spreader.

Figure 6. TSDHPT spreader.

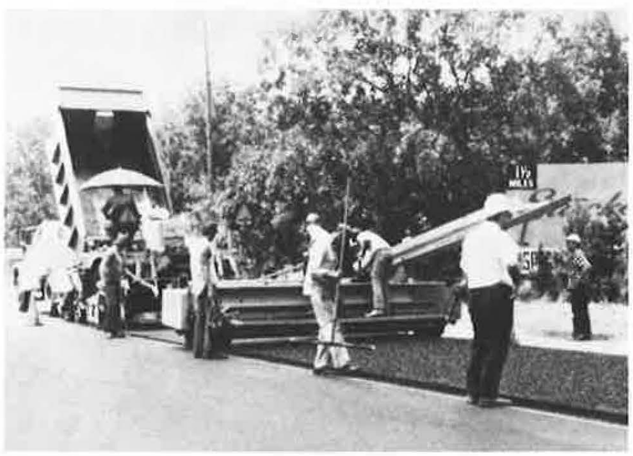


Figure 7. Bristowes MK V hydrostatic chip spreader.

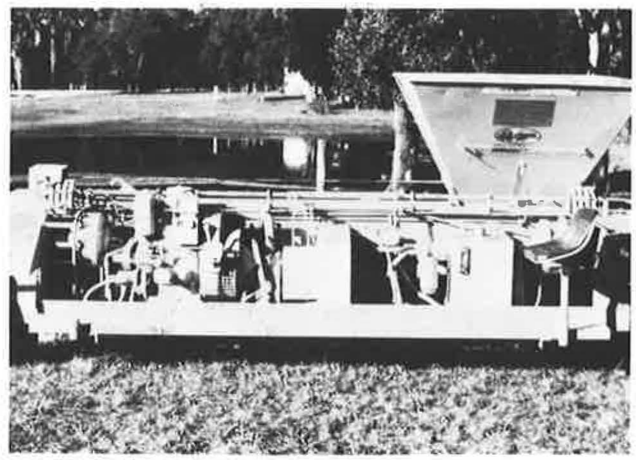
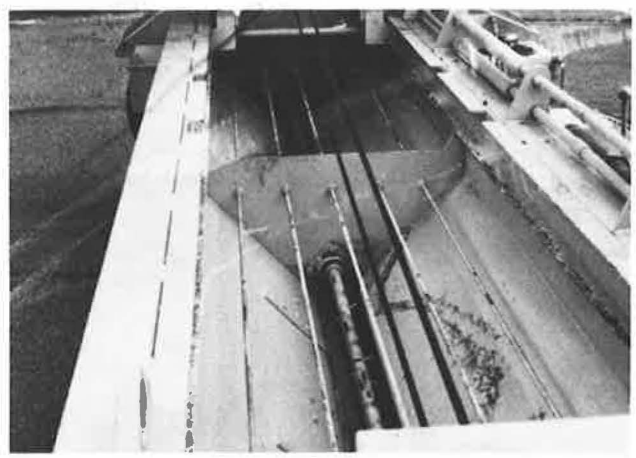


Figure 8. Spreader bin of Bristowes spreader.



er bin (see Figure 8). Inside the spreader bin is a stirring mechanism that aids the free flow of precoated aggregate through the adjustable gates onto the fluted drum. The spreader bin is also vibrated by mechanical hammers to aid the flow of precoated aggregate. The bottom opening controls the flow and can be adjusted during operation. For roadways narrower than the full width of the spreader, a portion of the spreader bin can be blocked off to prevent aggregate distribution.

Figure 9 shows some specific data on the Bristowes spreader. When completely charged with sprinkle aggregate, the spreader can distribute about 1,300 yd^2 of precoated sprinkle aggregate (average rate of 7.5 lb/yd^2) before it requires additional charging.

The Bristowes MK V machines have variable speed engines (from 1,200 to 1,500 rpm) and three-speed transmissions that allow a road speed of 3 to 300 ft/min. The engine starting controls and transmission are centrally located for easy access. The standard fluted drum is specifically designed for minus 0.75-in. precoated sprinkle aggregate and has been used on all projects placed thus far under the Demonstration Projects Program.

Although the spreader can be charged in a variety of ways, the most common is with a front-end loader. This method requires a truck driver, a loader operator, and a spreader operator to charge the spreader. The method of charging the Bristowes spreader must be carefully considered before the paving operation begins. If adequate shoulder width is not available to accommodate a nurse truck and front-end loader, it may be necessary to charge the hopper from the opposing travel lane. Figures 10 and 11 show two types of loading operations especially useful for limited shoulder widths. In Figure 10, a portion of the bucket is blocked out by tack welding a plate over a portion of its width. Another successful approach, and the one most commonly used, is to extend the sides of the hopper by using plate steel to accommodate an 8-ft-wide loader bucket, as shown in Figure 11 (note the limited working width).

In areas where there is adequate shoulder width, another means of charging the hopper is by using a conveyor system. Figure 12 shows a conveyor system used on a project in Michigan. This method requires only a truck driver and a spreader operator to charge the spreader and does not interfere with traffic. After the hopper is full of sprinkle aggregate, it is mechanically run across the entire width of the spreader to charge the storage bin. Once the spreader has been charged with the precoated sprinkle aggregate, it follows the paver and mechanically distributes the aggregate. The typical

Figure 9. Dimensions of most commonly used Bristowes spreader.

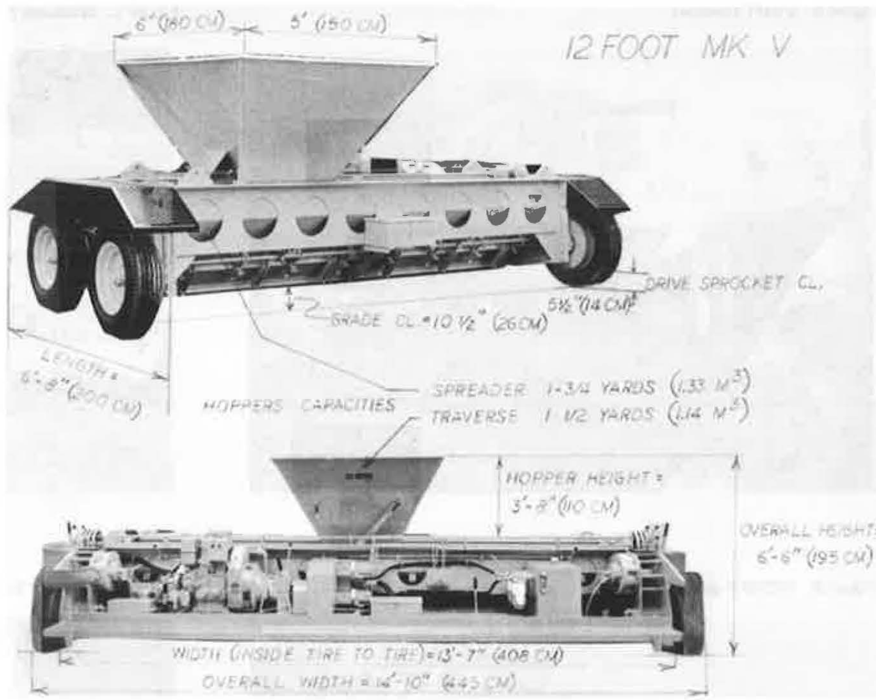


Figure 10. Charging Bristowes spreader with portion of loader bucket blocked off.

Figure 11. Charging Bristowes spreader with open loader bucket by using extension plates on traversing hopper.

Figure 12. Belly-dump truck towing conveyor used in Michigan to charge traversing hopper of Bristowes spreader.

aggregate distribution before rolling for both the Bristowes MK V and the TSDHPT tow-behind spreader has usually been good.

Occasionally, striations occur in the mat due to an uneven distribution of the sprinkle aggregate. This problem is only cosmetic and can usually be corrected by tightening the drive chains on the fluted drums, making sure that all the flutes are clear, and readjusting the spread rate. In addition to making sure that the spreader is in proper adjustment, it is sometimes necessary to remind the operator about the proper handling of the hydrostatic drive. The controls are sensitive, and quick starts or stops sometimes create the problems mentioned above.

A sample specification for sprinkle treatment of an asphalt concrete surface is available on request from the FHWA Demonstration Projects Division. This

basic format can be modified to fit the individual needs of an agency. However, certain design and construction requirements must be observed.

The sprinkle aggregate must be specified as a polish-resistant, closely graded, crushed stone with excellent frictional characteristics. Precoating of the sprinkle aggregate varies from 0.5 to 3 percent asphalt cement (AC) and should be completed several days before it is used on a project to allow adequate time for cooling. Antistrip agents are usually added to avoid any future stripping problems. Mixing time for batch plants usually varies from 40 sec to 1 min, and the optimum coating temperature is 275°F. The hot, precoated aggregate should not be stockpiled higher than 3 ft. If necessary, water can be cautiously used to aid in the cooling process.

After complete cooling, stockpiles can be heightened for convenience. The precoated aggregate can be stockpiled at either the plant site or the project site. Although stockpiled sprinkle aggregate may cake after a period of time, this is not considered a major problem. Usually, the individual aggregate particles can be separated easily during the loading and spreading operation.

The general procedure for the construction of a sprinkle-treated pavement is as follows:

1. Place the hot-mix asphalt surface course (made entirely of locally available aggregate);
2. Sprinkle cool, precoated, polish-resistant aggregate immediately behind the paver on the hot, uncompacted mat; and
3. Roll the mat to permanently embed the sprinkle aggregate and compact the mat.

It is recommended that a checklist of construction tips be prepared for both contractors and inspection personnel on sprinkle treatment construction projects to ensure good quality control of the operation. Specific areas for attention include the initial settings for the chip spreader, yield checks, application rate, agglomeration of chips, chip pullout, ability of the chip spreader to span the paving width, method of supplying chips to the spreader, and spreader adjustments during the operation. The Iowa DOT uses a checklist prepared in January 1980 to ensure quality control for its projects.

Table 1 gives information from some of the agencies that evaluated sprinkle treatment projects under the Demonstration Projects Program. The table includes sprinkle aggregate type, percentage and type of AC used for precoating, weather conditions during placement, sprinkle aggregate losses, and associated remarks.

Several different types of aggregates have been used for sprinkle treatment projects. Several different types of asphalt cement have also been used to precoat the aggregates. It is recommended that the type of AC used to precoat the sprinkle aggregate be the same type used to produce the hot-mix surface course because it is already available at the plant. The percentage of AC used to precoat the aggregate depends on the type of aggregate used. Typically, the lightweight or expanded aggregates require the highest percentages because of their increased porosity. It is recommended that a laboratory mix be designed to determine the amount of AC necessary to coat the sprinkle aggregate completely. This target value should be used in the initial production of the sprinkle aggregate at the hot-mix plant. Minor adjustments can be made at the plant to produce a 100 percent precoated sprinkle aggregate without using excess AC. Antistrip agents have been used on several projects to prevent future stripping problems. It is recommended that each type of aggregate selected for a sprinkle treatment application be tested for its susceptibility to stripping and that an antistrip be specified when necessary.

Table 1 also lists the rates of coverage for sprinkle aggregate. A majority of the projects placed thus far have used between 4 and 8 lb/yd². The heavier application rates (12 lb/yd² in Illinois, 11.7 lb/yd² in Kentucky, and 10 lb/yd² in Michigan) have resulted in higher sprinkle aggregate losses. It is recommended that the average spread rate be in the 3- to 4-lb/yd² range for lightweight aggregates and in the 5- to 8-lb/yd² range for heavier aggregates. Figure 13 shows a sprinkle-treated section of roadway (after 2 years of service) on which crushed gravel was spread at a rate of approximately 7.2 lb/yd². Note that the surface texture improves as the polish-susceptible surface mix wears away from the nonpolishing sprinkle aggregate so that the contact between the tire and the quality aggregate is improved.

After several years of experience with sprinkle treatment applications, TSDHPT recommends surface-area coverage of approximately 25 percent (see Figure 14). This rate of coverage has resulted in the suggestion by TSDHPT that 1 yd³ of sprinkle aggregate will cover 350 to 400 yd² of surface course, regardless of what type of sprinkle aggregate is selected.

Results from several past projects indicate that caution must be exercised to ensure good sprinkle aggregate retention. It is recommended that sprinkle treatment not be attempted if ambient temperature and wind velocity make compaction of the mat difficult. Sprinkle aggregate will not be properly embedded in a section of pavement that is allowed to cool before compaction. Even on warm days, the sprinkle aggregate will not be properly embedded in a section of pavement over which the paver is stopped for an extended period of time. It is therefore necessary that the paving operation remain continuous so that the surface of the freshly placed hot mix does not cool before embedding of the sprinkle aggregate. In general, if the temperature of the mat is such that proper compaction can be attained, the sprinkle aggregate has an excellent chance to be embedded and retained.

On the majority of projects reported to date, sprinkle aggregate losses have been negligible. The two highest losses (30 percent in Arkansas and 25 percent in Kentucky) are believed to be the direct result of controllable problems, including the use of elongated aggregate particles for the sprinkle treatment and the use of excessive spread rates. Other high losses (10 percent) were due to deficiencies in coating (caused by stripping) or to weather conditions. Therefore, it is recommended that

1. Sprinkle aggregate be properly graded and shaped and the aggregate gradation of the hot-mix mat be designed to ensure proper embedment of the sprinkle aggregate,
2. Sprinkle aggregate be precoated and the use of an antistrip agent be carefully considered,
3. Sprinkle aggregate be spread at a rate that will allow for the coverage of approximately 25 to 35 percent of the surface area, and
4. Sprinkle aggregate be placed only when weather conditions and contractor operations will permit proper embedment and compaction.

Table 2 gives the available skid-related data and information for projects constructed in cooperation with the Demonstration Projects Program. Average daily traffic (ADT), total vehicle passes (from construction until skid testing), 40-mph average skid

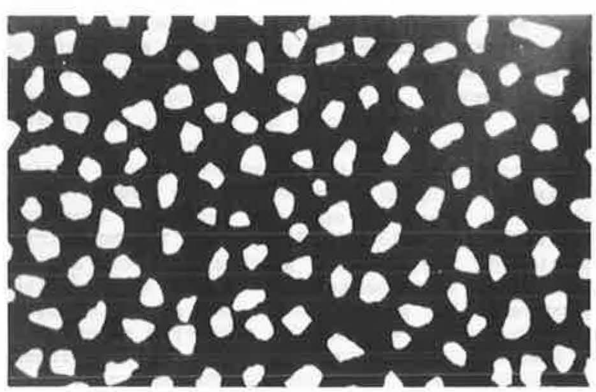
Table 1. Sprinkle treatment data from agencies that evaluated sprinkle treatment projects.

Agency	Highway	Type of Sprinkle Aggregate	AC Precoat Type	AC Precoat Percent	Anti-Strip Additive (%)	Rate of Coverage (lb/yd^2)	Weather During Placement	Sprinkle Aggregate Losses	Remarks
Arkansas State Highway and Transportation Department	US-62	3/8-in. crushed sandstone	AC-30	1.0		2.7	Cool	30% initially	Elongated particles did not adhere to the hot-mix material; subsequent projects had a minimum elongation value of 35 percent (width/length)
		0.5-in. crushed sandstone	AC-30	1.0		5.1	Warm	N	
	AR-7	0.5-in. crushed sandstone	AC-30	1.0		3.8	Warm	N	
FHWA Eastern Direct Federal District in Virginia	B.R. Parkway	Crushed sandstone (feldspar quartz)	AC-20	2.0	0.5	8.0	Hot	N	Minor losses during first few hours were negligible; no losses since initial period
Florida DOT	US-98	Crushed granite	AC-20	0.75		5.0	Cool	N	Placed in a hot sand mix
Georgia DOT	GA-156	0.5-in. curshed gravel	AC-20	1.25	1.0	7.8	Warm	N	No significant losses even when prematurely opened to local traffic; insufficient embedment occurred on several short sections due to paving delays that allowed the mat to cool before compaction and embedment
		Crushed granite	AC-20	1.25	1.0	7.2	Cool	N	
	GA-151	3/8-in. crushed gravel	AC-20	1.25	1.0	7.9	Warm	N	
Illinois DOT	IL-185	Crushed traprock	AC-10	1.3	0.5	6, 9, 12	Cool	3% max	Heaviest losses occurred in 12-lb/yd^2 section; no significant losses since initial period
Iowa DOT	US-69	Haydite and limestone	AC-10	1.5, 1.0		3.8, 9.1	Cool	N	Initial losses occurred where sprinkle aggregate was not fully embedded; complete embedment of sprinkle aggregate is difficult to achieve in cool weather
	IA-1	Haydite and dolomite	AC-10	2.0, 1.5		4.6, 7.5	Warm	N	
	US-20	Crushed limestone	AC-10	1.25		7.2	Warm	N	
	US-59	Haydite	AC-10	1.5		3.6	Warm	N	
	US-18	Quartzite	AC-10	1.0		6.4	Cool	5-10% initially	
	IA-38	Quartz and dolomite	AC-10	0.75, 1.25		5.5, 7.9	Cool	5-10% initially	
	US-30	Various	AC-20	1.25-3.25		7.5 avg	Warm	N	
Kentucky DOT	US-31E	Crushed granite	AC-20	1.6		11.7	Warm	25% initially	Losses were caused primarily by stripping of the sprinkle aggregate before placement and the heavy rate of coverage in the granite section; negligible losses have occurred since the initial period
		Crushed gravel	AC-20	1.7		4.5	Warm	10% initially	
		Crushed slag	AC-20	2.9		5.2	Warm	10% initially	
		Crushed quartzite	AC-20	1.7		5.5	Warm	10% initially	
Maryland State Highway Administration	MD-234	Crushed gravel	AC-20	1.0	0.25	7.5	Cool and windy	10% initially	Losses occurred on sections placed during cool, windy days with ambient temperatures of <50°F
Michigan DOT	US-23	Crushed gravel	85-100 PEN	1.25		3,5, 7.5, 10	Warm	N	More losses occurred in areas where spread rate was heaviest; all sections have similar skid values
Missouri Highway and Transportation Department	US-50	Crushed porphyry	60-70 PEN	1.0		7.1	Warm	None	No losses have occurred; pavement surface is being checked by observation-log system
Texas State Department of Highways and Public Transportation	US-59	Rhyolite	AC-20	2.0		360[a]	Hot	Some initial losses	Pavement surface is being checked by observation-log system; heavier losses are attributed to aggregate clusters in areas where hot, precoated sprinkle aggregate was used
		Sandstone	AC-20	1.5		400[a]	Hot		
	I-20	Lightweight	AC-20	4.0		350[a]	Hot	N	
		Lightweight II	AC-5	1.5		400[a]	Cool	5% max	

Notes: N = negligible; PEN = penetration.
Crushed indicates that the aggregate was crushed to meet gradation requirements. Cool is 40° to 70°F, warm is >70°F, and hot is >85°F.
[a]Square yards of surface course per cubic yard of sprinkle aggregate.

Figure 13. Sprinkle-treated roadway section after 2 years of service.

Figure 14. Aggregate surface-area coverage of 25 percent, as suggested by TSDHPT.



numbers, speed gradients, and texture measurements are summarized for comparison.

The majority of the demonstration installations were constructed on roadways with ADTs of less than 5,000. Although these ADTs vary, the total vehicle passes can be used to compare the surface wear characteristics of each project. Table 2 indicates that sprinkle treatment provides improved skid-resistance characteristics; however, further evaluation is necessary to determine long-term durability and skid resistance. All of the sprinkle treatment projects currently exhibit acceptable 40-mph skid number values (including four projects with more than 6 million vehicle passes). There are four installations where the average 40-mph skid number for sprinkle treatment is currently equal to or better than that

Table 2. Skid-related data for sprinkle treatment projects.

			Sprinkle Treatment					Control			
Agency and Highway	ADT	Total Vehicle Passes	Date	Type or Coverage	40-mph Skid Number	Speed Gradient	Texture	Date	40-mph Skid Number	Speed Gradient	Surface Mix Type
Arkansas State Highway and Transportation Department											
US-62	2,500	1,672,000	7/81		55	0.366	-	7/81	59	0.600	Crushed aggregate blend
AR-7	2,500	2,845,000	7/81		41	0.300	-	7/82	41	0.733	
US-62	2,500	-[a]									
FHWA Eastern Direct Federal District in Virginia											
B.R. Parkway	1,500	1,642,000	5/81		53	0.350	Outflow meter: sprinkle, 4.30; control, 51.18	5/81	56	0.550	Crushed aggregate blend
Florida DOT											
US-98	4,400	5,885,000	3/82		39.6	0.090	-	3/82	32.3	0.070	Polish susceptible
Georgia DOT											
GA-156	1,220	1,706,000	7/81		41		-	7/81	36		Crushed aggregate blend
GA-151	1,700	2,377,000	9/82		48	0.250		9/82	40	0.350	
GA-156	2,800	3,830,000	7/81		41						
Illinois DOT							Sand patch method				
IL-185	2,200	2,274,000	6/81	6 lb/yd^2	46	NA	0.033				
				9 lb/yd^2	42	NA	0.046	-	-	-	-
				12 lb/yd^2	43	NA	0.062				
Iowa DOT							Silly putty method				
IA-69	8,200	8,226,000	6/80	Haydite	46	0.700	-	6/80	28	0.800	Polish susceptible
				Avg	54	0.630	-		47	0.640	-
					53	0.440	-		47	0.440	Polish susceptible
					53	0.480	-		-	-	-
					46	0.320	-		-	-	-
				Avg	51	0.460	Avg surface texture, 0.0293		43	0.680	Polish susceptible
					54	0.280	Control, 0.0108		-	-	-
Kentucky DOT											
US-31E	4,900	5,065,000	7/81	Quartzite	53	0.433	-	7/81	57	0.667	Crushed aggregate blend
				Slag	56	0.433	-				
				Gravel	59	0.400	-				
				Granite	62	0.433	-				
Maryland State Highway Administration											
MD-234	2,425	1,622,000	Spring 1982		45	0.300	Sand patch method: sprinkle, 0.027; control, 0.011	Spring 1982	42	0.450	Crushed aggregate blend
Michigan DOT											
US-23			7/82	3 lb/yd^2	49	0.200	-	7/82	38[b]	0.400	Polish susceptible
				5 lb/yd^2	49	0.320	-		45[c]	0.440	
				7.5 lb/yd^2	50	0.240	-				
				10 lb/yd^2	53	0.320	-				
Missouri Highway and Transportation Department											
US-50	4,100	748,000	3/82	Avg	48	0.467	-	3/82	48	0.667	Polish susceptible
Texas State Department of Highways and Public Transportation											
US-59	15,200	18,898,000	11/80	Rhyolite	39	-	-	-	-	-	Various
				Sandstone	42	-	-	-	-	-	-
I-20	5,300	6,966,000		Lightweight	40	-	-	-	-	-	-
				Lightweight	43	-	-	-	-	-	-

Note: Blanks indicate not available.

[a]New. [b]Control 1. [c]Control 2.

of its comparative control section composed of skid-resistant, blended mixes. This is probably due to improved macrotexture and a greater concentration of quality aggregate on the surface of the sprinkle-treated pavement that comes in contact with the tires of a vehicle (Figure 2).

The surface texture of sprinkle treatment is consistently better than that of conventional dense-graded mixes. In addition, as the rate of coverage for sprinkle aggregate increases, the surface texture increases. It is important, however, not to increase the spread rate of sprinkle aggregate so that excessive loss occurs under traffic (as noted in Table 1). In order to allow sufficient room for sprinkle aggregate embedment, it is recommended that a 1.5-in.-thick (minimum) conventional surface course be used on sprinkle treatment projects. If a thinner mat is used, however, the aggregate in the mix retained on the No. 8 sieve should be kept under 50 percent. This also provides sufficient room for the sprinkle aggregate to be embedded.

Table 2 also indicates that the speed gradient for sprinkle-treated surfaces is almost always lower than that of conventional mixes. Speed gradient is a ratio of the change in skid number resulting from a corresponding change in speed [$G_{1-2} = (SN_2 - SN_1)/(V_2 - V_1)$]. If the speed gradient is low, it indicates a small change in skid number for a change in speed. Two desirable characteristics of sprinkle treatment are the combination of higher skid numbers at 40 mph and lower speed gradients. Additional discussion of speed gradients can be found in the Federal-Aid Highway Program Manual (9) and Instructional Memorandum 21-2-73 in that publication.

Table 3 summarizes information from three states where comparative skid tests (both treaded tire, ASTM E501, and smooth tire, ASTM E524) and texture measurements were reported. The data given in this table show several advantages of sprinkle treatment over conventional pavement, even when blended mixes were used. The texture measurements show that macrotexture is from three to seven times better on a sprinkle treatment surface than on a conventional pavement surface. Because the macrotexture is improved, contact between the tire and the quality aggregate is maintained as the amount of surface water increases, which reduces the potential of hydroplaning. It is also reasonable to assume that the splash and spray from passing vehicles would be reduced due to this increased surface macrotexture.

Table 3 also indicates a narrower range of skid-resistance values for sprinkle treatment sections when treaded-tire (ASTM E501) and smooth-tire (ASTM E524) skid test results are compared. The average range for the sprinkle treatment sections is only 9 points, whereas the average range for the control sections is 22 points. This confirms a better contact between the tire and the quality aggregate when the pavement surface is wet and indicates a reduction in hydroplaning effects when sprinkle treatment is used. Cars with either worn tires or tires with little tread would benefit from a safety standpoint because sprinkle treatment provides an improved skid resistant pavement surface.

A project-by-project summary of historical skid data, recent skid results at various speeds, and recent speed gradients for both sprinkle treatment and control sections is available on request from the FHWA Demonstration Projects Division. The speed gradients are graphically illustrated and indicate that the skid resistance of sprinkle treatment was better at higher speeds than that of the control sections even though the control section used a blended mix and had higher skid numbers at lower speeds. Improved macrotexture and lower speed gradients are two benefits of sprinkle treatment that contribute toward improved skid-resistance characteristics.

There are basically two gradations that have been

Table 3. Results of comparative skid tests and texture measurements on sprinkle treatment.

			Control Section				Sprinkle Treatment Section			
			40-mph Skid Number					40-mph Skid Number		
		Service Life	Treaded Tire (ASTM	Smooth Tire (ASTM	Texture			Treaded Tire (ASTM	Smooth Tire (ASTM	Texture Measure-
Agency	Highway	(years)	E501)	E524)	Method	Measurement	Type or Coverage	E501)	E524)	ment[a]
Illinois DOT	IL-185	2	51	28	Sand patch		6 lb/yd^2	44	34	0.033 in.
							9 lb/yd^2	42	35	0.046 in.
							12 lb/yd^2	42	39	0.062 in.
Iowa DOT	US-30 Type B 0.5-in mix	4	44	22	Silly putty	0.011 in.	Quartzite	52	42	0.036 in. avg
							Crushed gravel	47	38	
							Granite	48	40	
							Expanded shale	54	45	
							Coarse-grained dolomite	42	36	
							Limestone-dolomite	48	38	
	Type B 0.375-in mix		46	23		0.005 in	Quartzite	55	44	0.036 in.
							Crushed gravel	48	37	
							Granite	51	43	
							Expanded shale	57	47	
							Coarse-grained dolomite	45	39	
							Limestone-dolomite	44	35	
	Asphalt sand surface mix		51	31		0.003 in.	Quartzite	55	44	0.016 in.
							Crushed gravel	47	39	
							Granite	47	36	
							Expanded shale	54	39	
							Coarse-grained dolomite	43	31	
							Limestone-dolomite	43	28	
FHWA Eastern Federal District in Virginia	B.R. Parkway	4	54	33	Outflow meter	15.2 sec		55	54	1.9 sec

[a]Same method of measurement as for control section.

Table 4. Cost comparison for sprinkle treatment and blended mixes.

Depth of Pavement (in.)	Equivalent Weight (lb/yd²)	Tons of Mix per Mile	Cost ($)			Savings (%)	
			100% High-Quality Aggregate Mix (method 1)[a]	50-50 Blended Mix (method 2)[b]	100% Polish-Susceptible Aggregate Mix with Sprinkle Treatment (method 3)[c]	Method 3 over Method 1	Method 3 over Method 2
1.5	165	1161.6	13,939.20	9,873.60	8,448.00	39.4	14.4
2	220	1548.8	18,585.60	13,164.80	10,384.00	44.1	21.1
2.5	275	1936.0	23,232.00	16,456.00	12,320.00	47.0	25.1

[a] 1161.6 tons x $12/ton = $13,939.20. [b] 1161.6 tons x $8.50/ton = $9,873.60. [c] 1161.6 tons x $5/ton + $2,640 = $8,448.00.

used for the sprinkle aggregate. The first type is referred to as the 3/8-in. nominal size. This type requires 90 to 100 percent of the aggregate to pass a 0.5-in. sieve, 30 to 70 percent to pass a 3/8-in. sieve, and 0 to 10 percent to pass a No. 4 sieve. The second type is referred to as the 0.5-in. nominal size. This type requires 100 percent of the aggregate to pass a 0.75-in. sieve, 10 to 30 percent to pass a 3/8-in. sieve, and 0 to 5 percent to pass a No. 4 sieve. From a performance standpoint, the projects that incorporate sprinkle aggregate with a nominal size of 0.5 in. have shown slightly higher texture values.

Several types of aggregate were used for sprinkle treatment projects. The best skid-resistance results were obtained from aggregates with low Los Angeles abrasion loss, high Mohs hardness numbers, and low carbonate values. Although several manufactured lightweight aggregates were used, TSDHPT has concluded that this type of aggregate should not be used on high-volume facilities because it tends to break apart under heavy loading conditions. It is recommended that the highest-quality aggregate be used for sprinkle treatment. In general, the skid resistance of a properly constructed sprinkle-treated pavement will be similar to that obtained if the same quality aggregate used for the sprinkle treatment is used throughout the entire surface course. Also, the macrotexture for the surface will be improved to provide better contact between the tire and the quality aggregate. The use of the sprinkle treatment technique can provide any agency with improved skid-resistance characteristics while using only a small amount of quality aggregate.

ECONOMICS

The costs associated with the use of sprinkle treatment need to be analyzed on a project-by-project basis. Two primary considerations are the cost of spreading equipment necessary for constructing a sprinkle treatment project and the difference in cost to haul the amount of quality aggregate required to produce a blended mix compared to the amount of quality aggregate required for sprinkle treatment. Because the investment in spreading equipment is usually recovered as quickly as possible by contractors, initial sprinkle treatment projects are generally more costly. As sprinkle treatment is used more extensively in an area (Iowa and Texas, for example), the costs of sprinkle treatment can be expected to go down slightly because the equipment costs are spread out over a larger volume of work.

Direct cost savings can result from using sprinkle treatment because less aggregate is required than in conventional mixes. The results of a suggested method that can be used to compare cost savings of sprinkle treatment over blended mixes are given in Table 4. The obvious cost advantage of sprinkle treatment is the reduction in the amount of quality aggregate required to produce the desired skid-resistant pavement. When quality aggregates have to be shipped any appreciable distance, hauling costs increase.

The cost comparison presented in Table 4 is for a 1-mile-long, 24-ft-wide section of roadway (14,080 yd²). Locally available, polish-susceptible aggregate, with binder, costs $5/ton (no shipping charges). The quality aggregate, with binder, costs $12/ton including average shipping costs (source is 140 miles away) of $0.05/ton-mile or $7/ton on the base price (10). Blended mix means 50 percent high-quality aggregate and 50 percent polish-susceptible aggregate. A spread rate of 7.5 lb/yd² is used in the sprinkle treatment at an average in-place cost of $50/ton for an average cost per mile of $2,640 (52.8 tons/mile).

The following sample calculation has been used in Table 4:

$$(14{,}080\ \text{yd}^2 \times 165\ \text{lb/yd}^2)/(2{,}000\ \text{lb/ton}) = 1{,}161.6\ \text{tons}$$

The table indicates that through the use of sprinkle treatment savings can be realized over the cost of traditional types of paving mixtures. The primary difference in cost is a direct result of the reduced quantity of quality aggregate required and the associated shipping charges. It is recommended that this type of analysis be done to determine whether a sprinkle treatment application is feasible.

CONCLUSIONS

1. Sprinkle treatment is an alternative construction technique that will provide asphalt pavement surfaces with improved skid-resistance characteristics on low-volume roadways.
2. Sprinkle treatment reduces the amount of quality aggregate required to obtain skid-resistant pavement surfaces.
3. Sprinkle treatment can be economical if quality aggregates (required to obtain skid-resistance values) have to be shipped long distances.
4. Sprinkle treatment concentrates the quality aggregate on the pavement surface, which allows greater contact between the tire and the quality aggregate.
5. Sprinkle treatment increases macrotexture, which allows better surface drainage for improved contact between the tire and the quality aggregate and reduces the chance of hydroplaning.
6. Sprinkle treatment can be expected to provide skid-resistance values similar to those of a pavement in which the same quality of aggregate is used throughout the entire surface course on low-volume roadways.

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The contents of this report reflect the views of the author who is responsible for the facts and the ac-

curacy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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Evaluation of Moisture Effects on Asphalt Concrete Mixtures

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Water-induced damage of asphalt concrete mixtures has produced serious pavement distress, poor pavement performance, and increased pavement maintenance in the United States as well as in other areas of the world. This damage is mainly attributable to stripping of asphalt cement from aggregate and, in some cases, possibly to softening of the asphalt matrix. In an attempt to reduce the magnitude of the problem, various antistripping additives have been incorporated into asphalt mixtures. Unfortunately, there has been no way to evaluate their potential effectiveness or to evaluate proposed aggregate-asphalt combinations to determine their water susceptibility. Research results that describe how to determine the extent, nature, and severity of moisture-related damage to asphalt concrete mixtures used in pavements are presented. In addition, the causes of mechanisms that cause deterioration are discussed and related to those mixture and environmental factors associated with moisture damage. Included are evaluations of several testing techniques used to distinguish between aggregate-asphalt combinations that are susceptible to moisture damage and those that are not. Test methods included (a) the indirect tensile test on dry and wet cylindrical specimens, (b) the Texas freeze-thaw pedestal test, and (c) the Texas boiling test. Results of these evaluations show that both the Texas freeze-thaw pedestal test and the boiling test can be used to differentiate between known stripping and nonstripping asphalt mixtures. In addition, the tests can be used to evaluate the individual components of mixtures to determine which are water susceptible. A discussion is also presented of the most common treatments considered for use in alleviating the adverse moisture effects on pavement, adding antistripping agents or lime slurry, and pretreating stripping-prone aggregates. It is recommended that the Texas boiling test, which is simple and easy to conduct, be used for initial short-term screening and the Texas freeze-thaw pedestal test be used for final and long-term evaluations. However, if the mixture has high air voids content, it should be evaluated by using the indirect tensile test on dry and wet specimens.

Moisture-induced damage of asphalt concrete mixtures has produced serious distress, reduced performance and safety, and increased pavement maintenance in the United States as well as in other areas in the world. This damage is attributable to stripping of asphalt cement from aggregate and possibly, in some cases, to softening of the asphalt cement (1). Unfortunately, there has been no reliable way to evaluate proposed aggregate-asphalt combinations to determine their water susceptibility.

In response to this problem, the Center for Transportation Research (CTR) and the Texas State Department of Highways and Public Transportation (TSDHPT) through their cooperative research program initiated a project to study water-induced damage to asphalt mixtures in Texas. This study included an evaluation both of proposed test methods for ascertaining the water susceptibility of asphalt concrete mixtures and of the effectiveness of antistripping additives.

Several testing techniques were selected to determine whether they could accurately identify asphalt mixtures that are moisture susceptible. The tests finally selected for detailed laboratory evaluation and development were (a) the indirect tensile test on dry and wet specimens, (b) the Texas freeze-thaw pedestal test, and (c) the Texas boiling test.

The indirect tensile test was developed by Anagnos and Kennedy (2) and has been used extensively to characterize asphalt materials. The Texas freeze-thaw pedestal test (3) is based on a procedure suggested by Plancher (4). The Texas boiling test (5) is a synthesis of the several boiling tests