

Table 5. Costs of three sprinkle treatment projects (1980).

Cost Category	Mixture	Cost (\$/yd <sup>2</sup> )
Statewide average	1.5-in. mixture D	2.67
	1.5-in. mixture E	2.89
	0.625-in. open-graded asphalt friction course plus 1.5-in. binder mix	4.14
East Dubuque project	1.5-in. mixture C plus sprinkle chips	4.05
Vandalia project	1.5-in. mixture C plus sprinkle chips	2.80
Elizabeth project <sup>a</sup>	1.25-in. mixture C plus sprinkle chips or 1.25-in. mixture C plus 0.625-in. open-graded asphalt friction course	4.52

<sup>a</sup>1981.

roads and streets, except on the primary system, having a design traffic ADT of 2000 or less.

2. Mixture D or E should be used as surfacing on secondary and local roads and streets having a design traffic ADT greater than 2000, on all two-lane primary highways, on four-lane primary highways having a design traffic ADT of 25,000 or less, and on six-lane or greater highways having a design traffic ADT of 60,000 or less.

3. Only Mixture E should be used as surfacing on four-lane highways having a design traffic ADT greater than 25,000 and on six-lane or greater highways having a design traffic ADT greater than 60,000.

The 1980 costs are given in Table 5. Costs for both the East Dubuque and Elizabeth projects appear high, probably because of the small quantities involved. For the larger job at Vandalia, more

realistic cost comparisons can be made. In that case, the sprinkle treatment can compete with both mixture E and an open-graded asphalt friction course. It is also of interest to note that at Elizabeth the contractor had the option of placing either an open-graded friction course or a sprinkle treatment. The bid on the option for 9,114 yd<sup>2</sup> of either type of treatment was \$0.85/yd<sup>2</sup>, and the contractor chose the sprinkle treatment.

#### CONCLUSIONS

Friction numbers were good on all three projects. Macrotexture on the sprinkle-treated surface is excellent for the 12-lb/yd<sup>2</sup> chip spread rate, good for the 9-lb/yd<sup>2</sup> rate, but poor for the 6-lb/yd<sup>2</sup> rate. Based on limited data, reductions in both wet-weather and total accidents have been realized. It is therefore concluded that sprinkle treatment is a feasible, practical, and economical method for providing a safe riding surface.

An additional six sprinkle treatment projects were built in 1982. The extent of the future use of this type of treatment will depend on the overall evaluations of the nine projects built to date.

#### REFERENCE

1. Standard Specifications for Road and Bridge Construction. Illinois Department of Transportation, Springfield, Oct. 1, 1979.

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## Experience in Iowa with Sprinkle Treatment of Asphalt Pavements

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Experience in Iowa with the use of sprinkle treatments to improve the frictional characteristics of pavement surfaces is described. A 5.3-mile (8.5-km) research project was constructed in 1978 to evaluate sprinkle treatment surfaces. Six different sprinkle aggregates were rolled into three standard mixes used for asphalt surface courses. The sprinkle aggregates were quartzite, crushed gravel, granite, expanded-shale lightweight aggregate, dolomite, and a limestone-dolomite mixture. Precoating of the chips is one of the most important aspects of successful sprinkle treatments. Poorly coated chips result in substantial losses of sprinkle aggregate from the finished surface. Lowering temperatures after drying the sprinkle aggregate yields better coating. Manipulating coated chips in small piles and lightly sprinkling them with water just before use reduce congealment problems. Friction testing has shown the greatest improvement when quartzite and expanded shale were used: friction numbers were 8 to 10 points higher than those for nonsprinkled sections. Sprinkle treatments also yield greater macrotexture.

In recent years much emphasis has been placed on highway safety through geometric design factors, the diligent use and placement of manufactured materials such as guardrails, and the use of quality natural resource materials. In addition, conservation of natural resources and escalating costs are concerns that have been addressed in some form in many con-

ference programs and papers. Presented in this paper is a discussion of a method that is being used in Iowa as a means of treating the surface of asphalt pavements to increase texture characteristics and at the same time conserve the supply of high-quality, nonpolishing aggregates.

Open-graded friction courses have been used extensively as a means of improving the frictional characteristics of asphalt pavements. In Iowa this concept has been used in the construction of three experimental projects, but the results have been disappointing. Conclusions drawn from the open-graded friction course projects are that they

1. Quickly became impermeable because of dirt deposited on the pavement, and they lacked the edge drainage that is needed but that often requires an edge drop-off, a factor that is also recognized as a hazard;
2. Spalled excessively at reflected cracks; and
3. Required a minimum of 60 lb/yd<sup>2</sup> (32 kg/m<sup>2</sup>) of high-quality aggregate.

Sprinkle treating or chipping is a process of

spreading quality coarse aggregate (chips) on both bituminous and portland cement concrete pavements to provide improved frictional characteristics. This process has been used in Europe since the early 1960s. Experimental projects in which this process was used were first constructed in Virginia in 1969 (1) and in Texas in 1972 (2).

#### EXPERIENCE IN IOWA

Emphasis on skid-resistant, nonpolishing highway surfaces and the monitoring of such surfaces precipitated an in-house Skid Review Committee in late 1972. Since that time, increased emphasis on durable, nonpolishing materials in the design of asphalt mixes and aggregate selection has generated costly restrictions on the use of local materials, even to the point of importing traprock and quartzite from Wisconsin, Minnesota, and South Dakota.

In 1975, with the cooperation of the Office of Maintenance, the Iowa Department of Transportation (DOT) made its first attempt at sprinkle treatment. A dual-spinner tailgate spreader was mounted on a standard dump truck for use in sprinkle treating a new asphalt surface. The dump truck equipment was only marginally satisfactory because the lug tires of the truck left marks in the finished pavement, the uneven distribution of chips caused depressions in the surface, and the surface texture was not uniform. Nevertheless results of this experimental work did demonstrate increased surface texture and durability.

In 1976 a new dump truck was modified with an auxiliary transmission and a set of slick-surfaced tires. The dual-spinner spreader was mounted and surface sprinkle treatment was attempted again. Precoated chips were scheduled to be put on a test section; but, because of the lateness of the season and unusually cold fall weather, the project was delayed until 1977.

The test section placed with this unit in early 1977 also did not produce desirable results. The distribution of the chips was somewhat uneven, and the tire marks still showed even though no depressions were evident.

In June 1977 the Iowa DOT was advised by the E.D. Etnyre Company that a Bristowes Mark V hydrostatic chipping spreader manufactured in Middlesex, England, would be made available to the Iowa DOT through the company's distributor. In addition, the Bristowes Company advised that its assistant plant manager from England would spend 2 or 3 weeks to assist in the use of the spreader.

The Iowa DOT was eager to pursue the evaluation of sprinkle treatment further and immediately began the process of developing a specification for aggregates, gradation limits, and coating and application procedures.

Ten projects at various locations in the state were selected. Projects selected for sprinkle treatment were rural two-lane roadways with speed limits exceeding 40 mph (64 km/h) and traffic volumes in excess of 2,000 vehicles/day. Because all of the projects had been let without sprinkle treatment, it was necessary to develop extra work-order details and costs as well as construction timing to make the best use of the one available spreader. Eight of the projects were 1.5- to 2-in. (38- to 51-mm) thick, single-course resurfacing projects with 0.5-in. (13-mm) size mixes. The other two projects used the Cutler repaving procedure and the addition of 100 lb/yd<sup>2</sup> (54 kg/m<sup>2</sup>) of new 0.375-in. (10-mm) size mix.

Aggregates selected for sprinkle evaluation consisted of imported quartzite and granite and locally available dolomite, limestone, and crushed gravel.

Also selected was Haydite, a manufactured, expanded shale lightweight aggregate. Tests were performed in the central materials laboratory to determine the asphalt required to obtain a suitable asphalt coating. This was determined to be in the range of 1 to 1.5 percent for conventional aggregate to 2 percent for Haydite. The aggregate was coated in a conventional plant by using the same asphalt used in the mix. It was necessary to store the aggregate in a clean place and cover the stockpile.

In placing the chips with the spreader, several minor problems were recognized. The spreader had a span of 14 ft (4.3 m) and a clearance of only 5 in. (127 mm) above the roadway surface. Any significant edge drop would therefore cause the machine to scalp the fresh asphalt cement surface. In addition, keeping the outer wheel close to the roadway edge would cause encroachment into the opposing traffic lane. Refilling the spreader hopper presented a problem on roads with narrow shoulders, and it became necessary to use the traffic side for the nurse truck and charging loader.

It was found that a buildup of asphalt cement and fines in the drum flutes caused a problem in maintaining a uniform chip application rate. During extremely hot weather, the chips would occasionally congeal and clog the distributor hopper. Wetting the chips in the stockpile or as they were loaded minimized this problem.

Retention of the sprinkle aggregate caused some concern. Loss of the aggregate appeared to range from very little to 50 to 60 percent. Investigation indicated that some loss was occurring due to traffic pickup, apparently as a result of opening the new surface to traffic too soon. Some losses were attributed to excessive fine material causing minor chip concentration or "clumping," which prevented proper embedment of each individual chip. Additional losses may have resulted from attempting to embed the sprinkle aggregate in a coarse mix that did not provide sufficient matrix to hold it in place. The most significant cause of loss was attributed to attempting to place sprinkle aggregate when ambient temperatures were below 50°F (10°C).

The results of the 40-mph (64-km/h) friction tests performed on these projects yielded friction numbers ranging from 47 to 54 for the sprinkle sections and 29 to 42 for nonsprinkled control sections.

Another group of 12 projects was selected for further evaluation in 1978. The only change in the specifications was a gradation change to reduce the percentage of aggregate passing the No. 4 screen from a maximum of 10 percent to a maximum of 5 percent.

#### RESEARCH PROJECT

Surface courses on high-traffic roads in Iowa have historically been a type A, 0.5-in. (13-mm) topsize, dense-graded mix with a minimum of 65 percent crushed particles to provide good stability. The aggregates specified are to be nonpolishing.

Because one of the benefits of sprinkle treatment is to provide good frictional characteristics by reducing the amount of high-quality aggregates required, it was acknowledged that a research project would be desirable. The road selected for this research project was a 5.3-mile (8.5-km) section of old US-30 from just east of Ames to Nevada. Originally (in 1929), it was paved 18 ft (5.5 m) wide. It was widened to 24 ft (7.3 m) in 1953 and resurfaced with 3 in. (76 mm) of asphalt concrete in 1956. This was followed by an inverted penetration chip seal in 1974. The average daily traffic for the highway exceeds 4,000 vehicles/day.

The project was developed by dividing the 5.3

miles (8.5 km) into three mix-type sections to provide a comparison of the three surface textures that result from Iowa's dense-graded mixes. The mixes designed for this project were (a) a type B, 0.5-in.-topsize, dense-graded mix composed of 70 percent pit run gravel and 30 percent crushed gravel with 5.75 percent AC-20 grade asphalt cement; (b) a type B, 0.375-in. (10-mm) topsize, dense-graded mix composed of 55 percent crushed limestone and 45 percent natural sand with 6.25 percent AC-20 grade asphalt cement; and (c) an asphalt-sand surface course composed of 90 percent clean concrete sand and 10 percent limestone screenings with 8.0 percent AC-20 grade asphalt cement. Surface-course thicknesses were 1.5 in. (38 mm) for the 0.5-in. mix size and 1 in. (25 mm) for the others.

The three sections were each divided into seven subsections to provide for control sections and a test section for each of six sprinkle aggregates. Aggregates were to represent a cross section of readily available types from sources classified as to friction resistance type. Iowa's rating system classifies aggregates on the basis of Mohs hardness and grain size. Type 1 is composed of very hard-grained particles (Mohs 7 to 9) bonded together by a slightly softer matrix. Type 2 has a hardness range of 5 to 7. Type 3 consists of crushed traprock, gravel, and dolomites with a hardness range of 3.5 to 4 and 80 percent or more of the grains 120  $\mu$ m or larger in diameter. Type 4 has a hardness range of 3 to 4 and 80 percent of the grains 30  $\mu$ m or larger in diameter. Type 5 is lithographic and sub-lithographic in nature with grain sizes smaller than 30  $\mu$ m.

The aggregates selected were as follows (a skid resistance rating of 1 is good and a rating of 5 is poor):

Aggregate	Source	Iowa Skid Resistance Rating
Quartzite	New Ulm, Minnesota	2
Crushed gravel	Hallett Construction Company, Boone, Iowa	3
Granite	St. Cloud, Minnesota	2
Expanded shale	Carter-Waters Plant, Centerville, Iowa	3
Dolomite	Quimby quarry, Mason City, Iowa	4
Limestone- dolomite	Ferguson quarry, LeGrand, Iowa	4

The contract for the project was awarded on May 23, 1978, to the Iowa Road Builders Company of Des Moines, Iowa.

## CONSTRUCTION

### Surface Preparation

Surface preparation work was started on July 12, 1978. Areas requiring full-depth patches were identified. Deteriorated material was removed by using a "ditch witch" type of pavement cutter to saw the extreme limits of the patch. Then a jack hammer and an end loader were used to remove the broken material. Asphalt concrete was used as a patching material. Full-depth asphalt, properly placed, provides some pressure relief and reduces the problem of pavement blowups. Bulges created in the full-depth asphalt by pressure can be trimmed to restore a smooth surface. This in turn reduces the amount of patching required in future maintenance.

Surface patching was routine and consisted of chipping out the fractured asphalt material along cracks and joints and backfilling with new asphalt concrete material.

### Precoating of Sprinkle Aggregate

Precoating the sprinkle treatment aggregate is the most important but most tedious part of the sprinkle treatment process. Considerable loss of sprinkle aggregate had been observed on two projects treated in previous years. This was traced to a probable lack of coating or film thickness.

To aid in determining the maximum amount of asphalt needed to completely coat each aggregate, samples were coated in the laboratory. Three samples coated with different percentages of asphalt were observed visually. The recommended amount of asphalt was generally in a range from 1 to 1.5 percent for natural aggregates and 2 percent for the lightweight aggregate.

A batch-type plant was used to precoat the aggregate. Initially, small quantities of each aggregate were coated. The recommended amount of asphalt was used and the coating was observed. If it appeared inadequate (less than 99 percent coated), additional asphalt was added. Additional asphalt was often needed to obtain complete coating. This was attributed to some degradation of the aggregate and some increase in minus No. 200 material (finer than 0.075 mm) as the material passed through the dryer.

Congealing during stockpiling and cooling of the precoated aggregate were problems that had to be resolved. A suggestion had been made that applying cold water to the hot precoated aggregate would set the asphalt and make congealing less of a problem. It appeared that this approach was at least worth consideration. Therefore, the first load of each aggregate coated was sprayed with water as it was dumped. The cooling process was expedited by manipulation with an end loader. The next morning it was noted that some stripping of the asphalt had occurred on several of the aggregates. It was concluded that the stripping, although not critical, could not be tolerated. Further experimentation has shown that, when the freshly coated aggregate is placed in small piles [4 ft (1.2 m) or less in height] and manipulated slightly with an end loader, congealment is minimal. Light sprinkling of the aggregate with water at the time it was loaded for use eliminated most lumps by the time the load arrived at the spreader.

Stockpiles should be placed on a clean, hard platform and kept covered if there is any chance that they will become contaminated with fugitive dust, rain, or other foreign material. Because of the need for small stockpiles, the fear of congealment, and the limited paved areas for storing precoated aggregate, precoating was limited to about a 2-day supply.

### Laydown Operation

Placement of the mat was routine as far as equipment and method were concerned. The mix temperatures of the material as it was produced ranged from 275° to 320°F (135° to 160°C) for the 0.5-in. (13-mm) and 0.375-in. (10-mm) mixes. The sand mix was from 265° to 290°F (129° to 143°C). At the time of compaction, the 0.375-in. and 0.5-in. mixes ranged from 250° to 290°F (121° to 143°C), whereas the sand mix ranged from 250° to 275°F (121° to 135°C). These temperatures are quite normal for work being done when ambient temperatures are 70° to 80°F (21° to 27°C). Some slowing of production was experienced because of the methods used to charge the spreader.

The spreader is manufactured in England. It is diesel-powered, hydrostatically driven, and has dual controls to permit operation from either side. The shuttle hopper is mounted on a track and oscillates to distribute the chips evenly in a shallow trough.

The opening in the trough is adjusted and controlled by a gate setting mechanism. There is an agitator above the gate opening and there are mechanical hammers on the front of the trough to keep the chips flowing. The chips are picked up on the top of a fluted drum and delivered over the rear. The chips are dropped to the mat as the flutes reach a downward position.

The spreader distributes the chips uniformly; however, on occasion, a rippled appearance in the mat surface has been noted. This has been traced to the spreader; it was concluded that as the drive chains tend to loosen, the rotation of the drum becomes erratic and causes an uneven distribution of chips. By keeping the drive chains tight and maintaining a uniform speed that will keep the spreader at the desired proximity to the paver, this problem has been minimized.

#### Sprinkle Aggregate Application

The application rate of the sprinkle aggregate is controlled by the gate adjustment previously described. It is recommended that the gate initially be set slightly wider than the largest aggregate size. It can then be adjusted during operation to obtain the desired coverage, which for this project was 5 lb/yd<sup>2</sup> (2.7 kg/m<sup>2</sup>) of lightweight aggregate (specific gravity = 2.2) and 7 lb/yd<sup>2</sup> (3.8 kg/m<sup>2</sup>) of the natural aggregate (specific gravity = 2.6).

To prevent aggregate overlap at the beginning of each section, a canvas was spread under the spreader and the hopper was emptied. As each new section was begun, the gates had to be readjusted because of the differences in particle size and shape. To expedite the adjustment and to check on the application rate, a 3x3-ft (0.9x0.9-m) canvas was placed ahead of the spreader to collect 1 yd<sup>2</sup> of chip application, and the collected material was weighed on a scale. The desired application rate was determined, and the gates were readjusted as required. This process was repeated until the proper application rate was reached.

Appearance was also used as a factor in determining and adjusting to the best application rate because the difference in aggregate gradation has an effect on the results. That is, chips with near-maximum percentages passing the 0.375-in. screen have a greater tendency to pile up, which gives the appearance of insufficient coverage. In addition, smaller particles are often not embedded deep enough to be permanently retained. Both conditions have resulted in some loss of sprinkle aggregate. For these reasons, the specifications were changed for future work. Beginning in 1979, a single size of aggregate meeting the following gradation was required:

Sieve Size	Percentage Passing	
	Minimum	Maximum
0.75 in.	100	
0.375 in.	0	15
No. 4	0	5
No. 200		1.5

A cubical aggregate shape is more desirable than slivered particles.

#### Compaction

Compaction of the sprinkled surface was routine. Minor delay was experienced because of some difficulty in charging the shuttle hopper. Some contractors are experimenting with methods to develop a rapid charging method. Once this is perfected, the

sprinkle treatment and roller operations can closely follow the paver.

The need to delay the opening of sprinkle-treated surfaces to traffic in order to reduce the potential of dislodging the sprinkle aggregate was part of this research project. However, since progress was slowed somewhat because of the need to change sprinkle aggregates every 1,200 ft (366 m), it was impossible to determine a reasonable minimum time. Project records indicate that traffic was kept off the fresh surface from 2 to 7 hr, the 2-hr period being at the end of the day. No dislodging of the sprinkle aggregate by traffic was noted on this project.

#### FRICITION TESTING

Friction tests have been made several times since completion of the project. The first test was made on August 10, 1978, just after the project was completed. Subsequent tests were made on August 28, September 15, and October 18, 1978, May 15, 1979, and at least once a year since. Tests were made at 40 mph (64 km/h) in accordance with ASTM E-274 by using an ASTM E-501 standard tread tire.

Graphs have been prepared to illustrate how frictional characteristics are affected by sprinkle treatment. Figure 1 shows the effects on the 0.5-in. (13-mm) mix size. Friction numbers are higher on all sprinkled sections except the one where a coarse-grained dolomite was used. Granite, limestone-dolomite, and crushed gravel have improved friction numbers by 3 to 5 points, whereas quartzite and expanded shale produce numbers that consistently run 8 to 10 points higher than those for the non-sprinkled section.

Figure 2 shows that friction numbers for the control section where a 0.375-in. (10-mm) type B mix was used are about 4 points higher than the control section where a 0.5-in. (13-mm) mix size was used. Coarse-grained dolomite and the limestone-dolomite blend have consistently failed to improve the friction numbers. Crushed gravel and granite show a slight benefit, and quartzite and expanded shale show results 8 to 10 points better.

Figure 3 shows friction number results for the asphalt sand surface. Friction numbers for the control section are consistently in the 47 to 52 range. Quartzite and expanded shale are the only two aggregates that improved the friction numbers.

The combined results shown in the three figures for the control sections indicate that the friction numbers increase as the mix gradations become finer [0.5 to 0.375 in. (13 to 10 mm) to sand]. This would appear to indicate that friction numbers are a function of the surface microtexture. However, there is an indication that the friction numbers for the sprinkle-treated sections become more a function of the aggregates--i.e., limestone and dolomites in the lower range, granite and crushed gravel in the midrange, and expanded shale and quartzite performing best.

Figures 4-6 show the most significant indication of the benefits of sprinkle treatment. In 1982 testing was begun with a smooth-treaded tire (ASTM E-524-76). To show this graphically, results from all of the sprinkle-treated sections have been averaged and compared with results for the control sections. Here again, it is noted that with the smooth tire, friction numbers for the control sections increase as the surface macrotexture (mix size) decreases. It can also be noted that the range in the control sections is uniformly wide (17 to 23 points); but, when the sprinkle treated sections are compared, the band is narrowed significantly (9 to 12 points).



## TEXTURE

Surface texture measurements using the "silly putty" method (4) were made immediately after the completion of the project. Measurements were also made in April 1979 (after 8 months of traffic) and the results were as follows.

Mix	Average Texture Depth (in.)		
	Nonsprinkled	Sprinkled	% Increase
0.5 in.	0.012	0.026	118
0.375 in.	0.007	0.031	364
Sand asphalt	0.014	0.026	86

The texture depths from the 0.5 in. (13 mm) mix, the 0.375 in. (10 mm) mix, and the sand asphalt were averaged for each sprinkle aggregate (Figure 7) to show graphically the significant texture depth im-

Figure 1. Friction number of sprinkle treatments on type B 0.5-in. mix 4 years after construction.

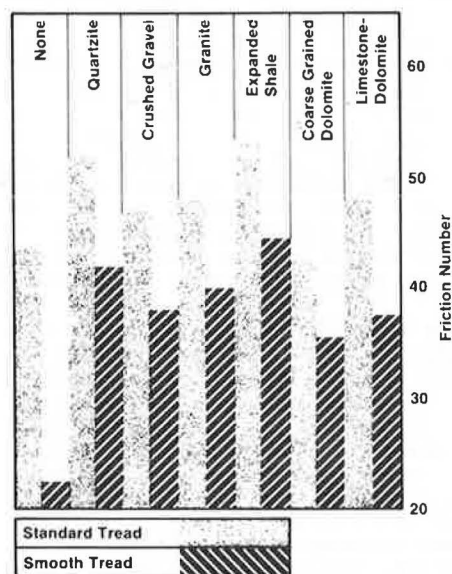
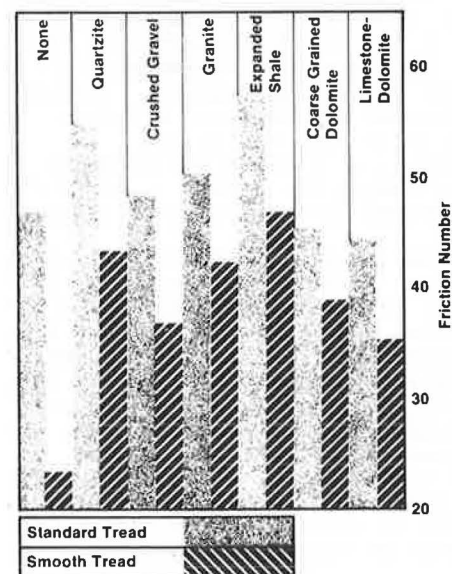


Figure 2. Friction number of sprinkle treatments on type B 0.375-in. mix 4 years after construction.



provement. The average texture depth of the non-sprinkled sections was 0.011 in. with the average of all sprinkle treated sections averaging 0.028 in. (0.70 mm) or 155 percent greater.

## POSTCONSTRUCTION PERFORMANCE

The initial difference, and perhaps one of the more significant differences, noticed in comparing the sprinkle-treated surface with a nontreated surface is that during a rainstorm the splash or spray from

Figure 3. Friction number of sprinkle treatments on asphalt sand surface course 4 years after construction.

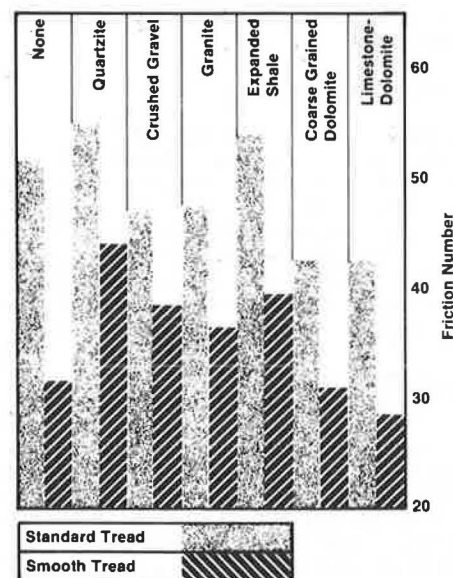


Figure 4. Comparison of friction numbers for sprinkle-treated sections and control sections on a type B 0.5-in. mix.

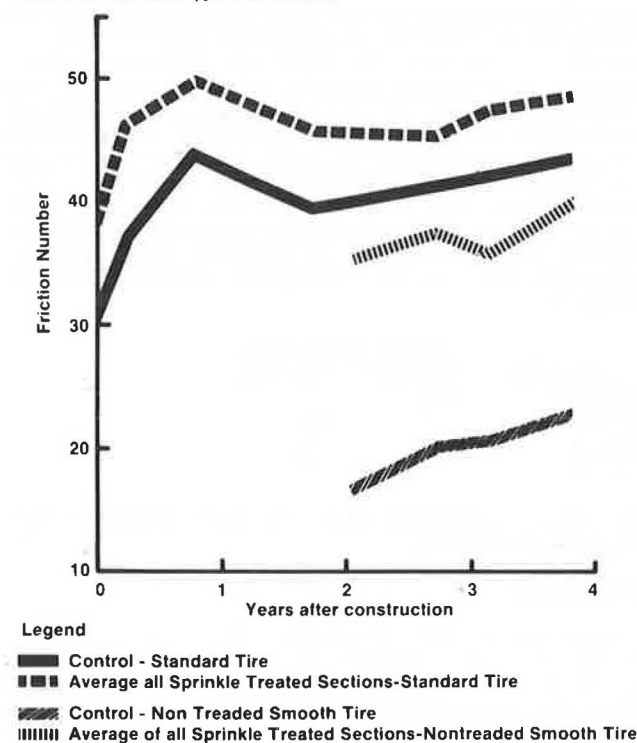
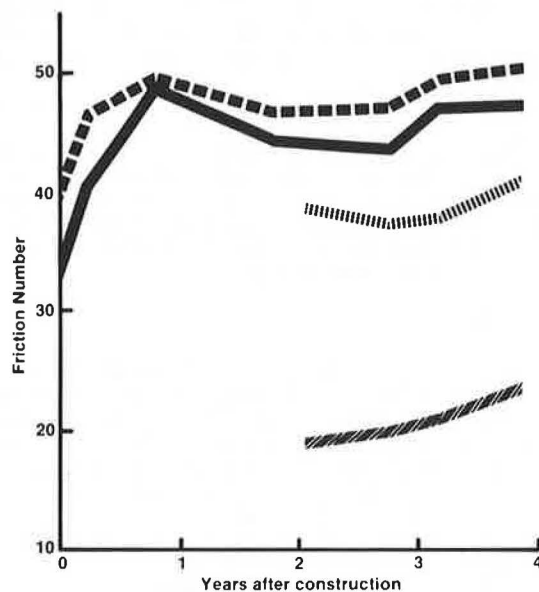


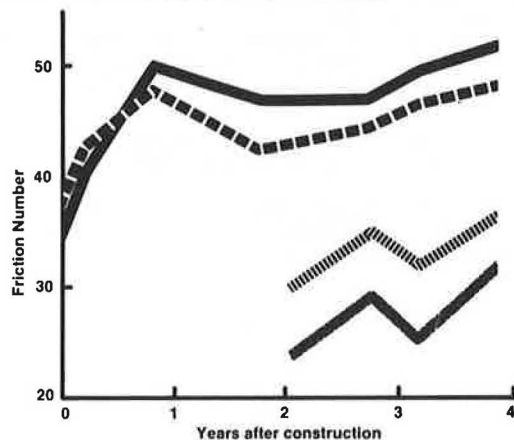
Figure 5. Comparison of friction numbers for sprinkle-treated sections and control sections on type B 0.375-in. mix.



#### Legend

- Control - Standard Tire
- - - Average all sprinkle treated Sections-Standard Tire
- ... Control - Non Treaded Smooth Tire
- . - Average of all Sprinkle Treated Sections-Nontreaded Smooth Tire

Figure 6. Comparison of friction numbers for sprinkle-treated sections and control sections on an asphalt sand surface course.



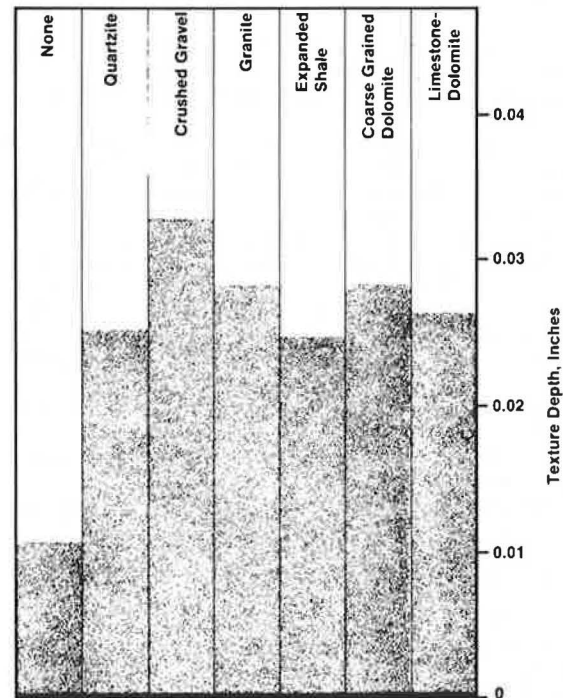
#### Legend

- Control - Standard Tire
- - - Average all Sprinkle Treated Sections-Standard Tire
- ... Control - Non Treaded Smooth Tire
- . - Average of all Sprinkle Treated Sections-Nontreaded Smooth Tire

tires of oncoming vehicles is considerably less with the treated surface. It is also noted that night-time headlight glare from a wet pavement is significantly less with the treated surface.

The winter after construction was severe, with above-normal snow and ice and below-normal temperatures. Maintenance reports on road condition variability during inclement weather indicate that snow and ice are inclined to adhere to the sprinkle-treated surface more rapidly than to an untreated surface. This is reported as being a problem with both salted and nonsalted roads. However, incidents have been reported in which snow or ice melted more

Figure 7. Average texture depth of nonsprinkled and sprinkle-treated surfaces.



rapidly on a treated section than on an untreated section because of retained brine. But this is a condition that can generally be anticipated when a good macrotexture has been obtained.

#### ECONOMIC BENEFIT

The cost savings derived by using sprinkle treatments depend on the proximity of the project to nonpolishing aggregate. A project in southwest Iowa (where nonpolishing aggregate is nonexistent) that would require either 35 percent of the aggregate in a 1.5-in. (38-mm) surface course to be nonpolishing or the surface to be sprinkle treated is discussed below as an illustration of the possible savings. Assuming that the nonpolishing aggregate for the sprinkle treatment is quartzite from Del Rapids, South Dakota, the following comparisons can be made.

One mile (1.6 km) of 1.5-in. (38-mm) surface course requires 1,042 tons (945 Mg) of aggregate. If the surface course used 100 percent local limestone at \$4.95/ton (\$5.45/Mg) and 53 tons (48 Mg) of quartzite sprinkle treatment costing \$5.50/ton (\$6.06/Mg) plus \$0.10/ton-mile (\$0.07/Mg-km) for 190 miles (306 km), plus \$40/ton (\$44/Mg) to coat and spread, the cost would be \$8,576/mile (\$5,328/km). Costs for the same mile using 677 tons (614 Mg) of limestone and 365 tons (331 Mg) of quartzite in the surface course would be \$3,351 for limestone and \$8,942.50 for quartzite, for a total of \$12,293/mile (\$7,638/km). The savings realized by using the sprinkle treatment would be \$3,717/mile (\$2,310/km). Significant savings in haul costs alone could be realized soon after the haul exceeds 70 miles (113 km), which would not be uncommon in many areas.

In addition to the savings in the cost of aggregate, natural resources that include the high-quality aggregate and gasoline for transporting that aggregate would be conserved.

#### CONCLUSIONS

The following conclusions were derived from this research project:

1. Hard, durable stone that resists polishing should be used for sprinkle treatment of paved surfaces.

2. A single size of aggregate should be used for the best results. A 0.75x0.5-in. (19x13-mm) size is most appropriate for the type of spreader currently being used.

3. A heavy coating of asphalt can be applied to the aggregate without fear of congealment if stockpiles are kept small and are manipulated carefully during the cooling process.

4. A small amount of water added just before application will aid in keeping the aggregate friable and free-flowing. It will also aid in reducing the amount of asphalt buildup on the spreader flutes.

5. Sprinkle-treated surfaces result in an improvement of the friction numbers of asphalt pavement.

6. Sprinkle treatment increases the surface macrotexture significantly.

7. Sprinkle treatment tends to reduce the amount of vehicle tire spray during wet weather.

8. Sprinkle treatment tends to reduce headlight glare from wet pavement surfaces at night.

9. Under some conditions, snow and ice removal may be more difficult on sprinkle-treated sections.

The Iowa DOT has been impressed by the results of sprinkle treatment to the extent that it is considered as a surface course treatment on resurfacing of two-lane highways where traffic exceeds 2,000 vehicles/day and when the geometrics or aggregates available indicate that it may be a cost-effective safety measure. Iowa has been sprinkle-treating approximately 100 miles/year, and as of 1981 had approximately 420 miles of sprinkle-treated surfaces. Approximately 150 miles were sprinkle-treated in 1982. This total includes 13 miles of the eastbound lanes of I-80 in west-central Iowa. Traffic volumes in this area exceed 10,000 vehicles/day.

One technique not noted in this research effort is that chips will coat better at low temperatures (240° to 250°F). This can be accomplished by slowing the drying process, holding the hot chips in a batch bin until they have cooled somewhat, or pre-drying and rerunning them through the plant with little or no heat. As indicated previously, stock-

piles must be kept small and shallow until the asphalt has set. After the asphalt has cooled considerably, water can be used as a means of preventing congealing. Water is also needed at the time when the chips are used to reduce the tendency for sticking in the chip spreader.

Iowa contractors have tried numerous ways of charging the chip spreader. None has yet developed a means that is suitable or desirable for all situations because shoulder width and traffic conditions vary considerably from job to job. Most of the contractors use end loaders, but some have modified Flowboy trucks and concrete dumpsters with augers or conveyors for a satisfactory job.

#### ACKNOWLEDGMENT

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