Effect of Material, Design, and Construction Variables on Seal-Coat Performance

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A field study conducted at the Pavement Durability Research Facility of the Pennsylvania Transportation Institute and on Pennsylvania Route 64 to determine the effect of specific construction, traffic, and materials variables on the performance of bituminous seal coats is described. The condition of the existing surface (worn or leveled), emulsion application rate, rolling patterns, time between construction operations and opening to traffic, and polymer modification were among the study variables. Accelerated traffic was applied to the sections for 1 year, and the performance, skid resistance, visual evaluations, and mean texture depth were documented. Design and construction variables were found to diminish the other study variables. Conclusions are presented that relate to the different phases of a seal-coat operation, including surface preparation, materials selection and specification, seal-coat design, construction procedures, and quality control.

The application of a seal coat is recognized as one of the most efficient and economical maintenance techniques used to extend pavement life. During 1987, the Pennsylvania Department of Transportation (PennDOT) applied seal coats to more than 5,000 mi of roadway, requiring more than 14 million gal of asphalt emulsion. Specifications, policies, guidelines, and a seal-coat design method have been developed by PennDOT for district maintenance personnel (*1*,*2*). A number of seal-coat design procedures have been developed (*3*). More recently, procedures have been published by McLeod and Holmgreen (*4*–*6*). The procedure adopted by PennDOT has been largely patterned after the one developed by McLeod (*7*). In spite of this information and extensive training, the service life of some seal coats has been shorter than desirable, often resulting in a severe loss of skid resistance through flushing of the surface (*2*). Epps et al. wrote a review of the factors that influence the longevity of seal coats (*8*).

Although considerable attention has been given to design procedures, much less has been given to materials, construction, and traffic control variables. Therefore, this study was initiated to investigate the effect of these variables, as well as the effect of design variables on seal-coat performance. The study was conducted at the Pavement Durability Research Facility of the Pennsylvania Transportation Institute (PTI) and on a section of Pennsylvania Route 64 near the Pennsylvania State University. The test sections were monitored during construction and for 1 year after construction to evaluate their relative performance. An extensive laboratory testing program also was conducted to characterize the aggregate and binders used in the study.

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EXPERIMENT DESIGN

The research plan was divided into two experiments: a primary construction-related experiment and a secondary material-related experiment. Elements of each experiment were incorporated both at the Pavement Durability Research Facility and on Route 64. A description of each experiment is given below.

Primary Construction Variable Experiment

Four variables were included in this experiment:

1. Pavement condition (two levels): worn ID-2 or new ID-2 leveling;
2. Emulsion rate (two levels): high or low;
3. Number of roller passes (two levels): 1 or 3;
4. Traffic control (delay before application of traffic) (three levels): 2, 8, or 24 hr.

Twenty-four test sections, each approximately 50 ft long, were used to accommodate each of the 24 variable combinations at the Pavement Durability Research Facility. The ID-2 mixture is a typical surface course mixture used by PennDOT; the maximum size of the aggregate is ⅜ in.

Secondary Material Variable Experiment

Three variables were included in this experiment: emulsion type, aggregate gradation, and age of leveling course. A summary of the characteristics of each of the 14 test sections in this experiment is presented in Table 1.

Route 64 Experiment

Four variables were introduced in 18 test sections on Route 64: emulsion type, number of roller passes, existing pavement surface condition, and time of traffic control. Each test section, which was approximately 2,250 ft long, is described in Table 2.

TRAFFIC

Traffic at the Pavement Durability Research Facility was started in August 1988 and continued through August 1989. It consisted of a tractor pulling two single-axle trailers loaded to the

TABLE 10 COMPARISON OF PERCENT REFLECTIVE CRACKING AND PERCENT RETENTION AT 0°F FROM VIALIT TEST FOR EACH SECTION

% Reflective Cracking	% Retention at 0°F	Section	Product
0	98	4	AR 1000 modified with crumb rubber
10	88	5A	AC10
13	8	2	AR 2000
13	60	5C	AC10
19	75	3A	AC20R
19	67	7C	Kraton modified AR 1000
51	87	7B	Kraton modified AR 1000
58	33	9C	AC10R
75	92	6A	EVA modified AC10
83	43	6C	EVA modified AC10
90	82	9A	AC10R
99	36	10	AR 2000
100	5	8C	Liquid styrene modified AR 4000
113	34	8B	Liquid styrene modified AR 4000

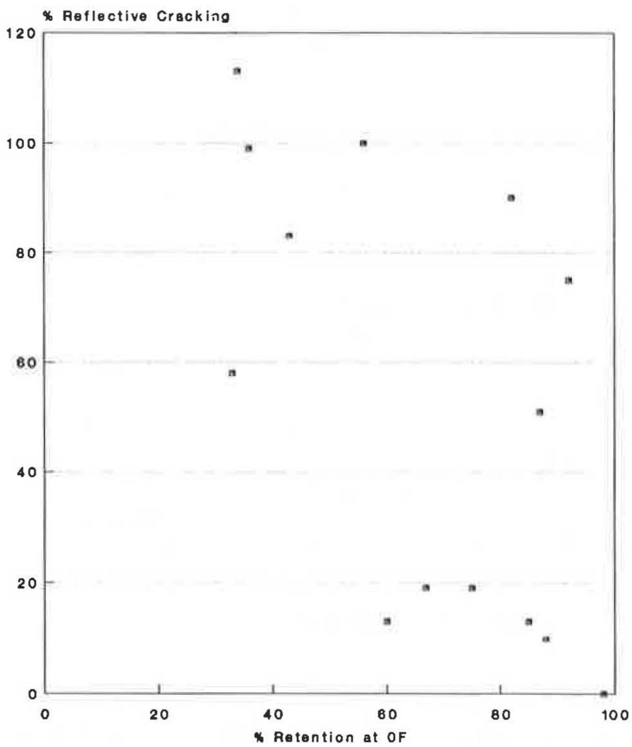

FIGURE 16 Correlation between percent retention at 0°F and percent reflective cracking.

There is no correlation between aggregate retention at 0°F and percent reflective cracking. However, there is also no correlation between overall condition and reflective cracking (Figures 16 and 17). These comparisons suggest that reflective cracking is not just a function of the binder-aggregate system but may be dependent on the brittleness of the binder.

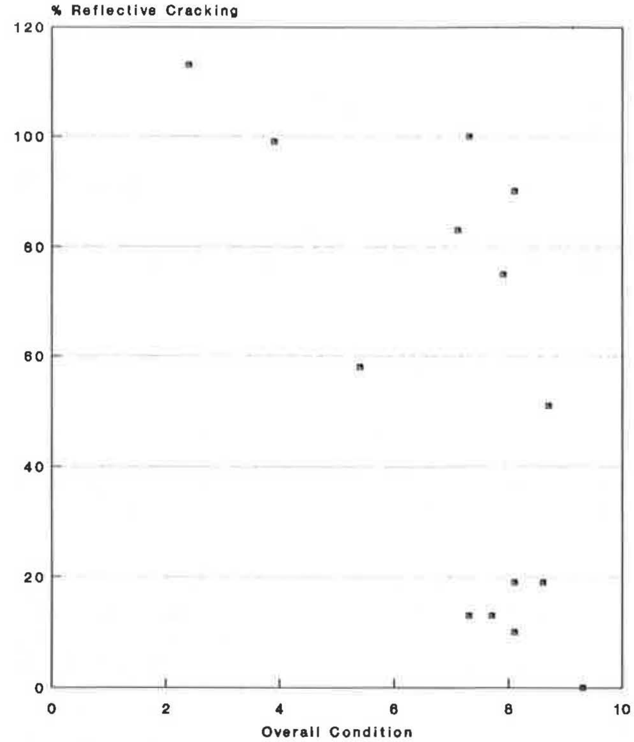

FIGURE 17 Correlation between overall condition and percent reflective cracking.

CONCLUSIONS

1. The field Vialit-time series testing did not correspond to laboratory Vialit-time series testing because of the variation in curing temperature of the field samples.
2. The laboratory Vialit-temperature series can detect the effects of aggregate gradation on different binders.
3. Aggregate retention of the sample cured at 0°F is a good indicator of overall chip-seal performance. Ratings of 8.0 or greater are likely for overall condition and aggregate retention if the percent aggregate retention for the laboratory sample cured at 0°F is greater than 60 percent.

REFERENCES

1. *Standard Specifications.* Nevada Department of Transportation, Carson City, 1984.
2. *Standard Specification for Construction of Highways, Streets, and Bridges.* Texas State Highway and Public Transportation Department, Austin, 1972.

Publication of this paper sponsored by Committee on Characteristics of Bituminous-Aggregate Combinations To Meet Surface Requirements.

TABLE 1 SUMMARY OF CHARACTERIZATION FOR EACH TEST SECTION OF SECONDARY MATERIAL VARIABLE EXPERIMENT AT PAVEMENT DURABILITY FACILITY

Section No.	Emulsion[1] Type	Aggregate Gradation	No. of Roller Passes	Pavement Condition
S-1	E-3	Single-Size	1	Worn ID-2
S-3	E-3	Graded	3	Worn ID-2 Leveling[2]
S-4	E-3	Graded	1	Worn ID-2 Leveling
S-5	E-3	Graded	1	New ID-2 Leveling
S-6	E-3	Graded	1	New ID-2 Leveling
S-7 (S-5)[3]	Neoprene	Graded	1	New ID-2 Leveling
S-8	E-3	Graded	1	New ID-2 Leveling
S-9 (S-6)	SBR	Graded	1	New ID-2 Leveling
S-10	E-3	Graded	1	New ID-2 Leveling
S-11 (S-8)	SBS 1	Graded	1	New ID-2 Leveling
S-12 (S-10)	SBS 2	Graded	1	New ID-2 Leveling
S-13	E-3	Single-Size	3	New ID-2 Leveling
S-14	E-3	Single-Size	1	New ID-2 Leveling

1 E-3 is an ASTM CRS-2 emulsion
SBR is a styrene-butadiene-copolymer-modified emulsion (2.8 percent)
SBS-1 is a styrene-butadiene-styrene-modified emulsion from manufacturer 1 (2.8 percent)
SBS-2 is a styrene-butadiene-styrene-modified emulsion from manufacturer 2 (3.0 percent)
Neoprene is a neoprene-modified emulsion (2.8 percent)

2 Worn ID-2 Leveling was placed in 1987 with no traffic until after the seal coat was applied.

3 Numbers in parentheses correspond to the control for the sections that were constructed with modified binders.

TABLE 2 SUMMARY OF CHARACTERISTICS OF SEAL-COAT TEST SECTIONS CONSTRUCTED ON ROUTE 64

Section No.	Emulsion Type	No. of Roller Passes	Traffic Control (hours)	Existing Pavement Condition
Control North	AC-10 Control	1	2	3-Year Seal Coat
Control South	AC-10 Control	1	4	3-Year Seal Coat
1a	Neoprene	1	2	3-Year Seal Coat
1b	Neoprene	2	2	3-Year Seal Coat
1c	Neoprene	2	4	Thin Overlay
1d	Neoprene	1	4	Thin Overlay
2a	SBR	1	4	3-Year Seal Coat
2b	SBR	2	4	3-Year Seal Coat
2c	SBR	2	2	Thin Overlay
2d	SBR	1	2	Thin Overlay
3a	SBS	1	4	Thin Overlay
3b	SBS	2	4	Thin Overlay
3c	SBS	2	2	3-Year Seal Coat
3d	SBS	1	2	3-Year Seal Coat
4a	SBS	1	2	Thin Overlay
4b	SBS	2	2	Thin Overlay
4c	SBS	2	4	3-Year Seal Coat
4d	SBS	1	4	3-Year Seal Coat

legal axle limit of 22,400 lb per axle. Two 2-person crews operated the truck approximately 16 hr a day. A total of 73,400 truck passes were applied during the monitoring period.

The traffic on Route 64 consisted of trucks and automobiles. The average daily traffic (ADT) for Route 64 was reported by PennDOT as 2,600 vehicles per day per lane. The traffic consisted of 9 percent trucks.

EMULSIONS

A standard E-3 (ASTM CRS-2) emulsion was used to construct all test sections except the polymer-modified sections. The emulsion met all of PennDOT's specification requirements. The properties of the base asphalt cement used to manufacture the E-3 emulsion satisfied the requirements for an AC-10 asphalt cement. The four modifiers used in the secondary experiment and on Route 64 are described in Table 1. A comprehensive set of conventional and nonconventional laboratory tests was performed on all of the emulsions used on the project, as well as on the emulsion residues. The results of the tests may be found elsewhere (*8,9*).

AGGREGATE PROPERTIES

The aggregate supplied for this project, selected by PennDOT personnel, is a heterogeneous siliceous, glacial gravel produced at the Fairfield Township operation of Lycoming Silica Sand Company. The results of tests performed on the aggregate, including gradations for both the graded material and the single-sized stone, follow.

	Percent Passing	
Sieve Size	*Graded*	*Single-Sized*
½	100	100
⅜"	89	92
#4	21	8
#8	8	4
#16	4	3.5
#30	4	–
#200	1	1

Additional data are as follows:

- Hydrometer analysis (percent finer than given size expressed as percent of total aggregate:
  - –.025 mm, .55;
  - –.008 mm, .29; and
  - –.001 mm, .13;
- Flakiness index (average least dimension): .2 in.;
- Los Angeles abrasion (percent wear): 30 (the maximum is 40);
- Crush count (percent crushed faces): 94;
- Bulk specific gravity: 2.62; and
- Absorption: 2.15 percent.

The aggregate meets the grading requirements for a Pennsylvania IB stone (AASHTO 8) that is to be used for seal-coat work. All other PennDOT specification criteria were met by this aggregate.

PRECONSTRUCTION EVALUATION AND SEAL-COAT DESIGN

The rut depths and surface texture of the pavement sections at the Pavement Durability Research Facility and on Route 64 were evaluated before seal-coat construction. At the Pavement Durability Research Facility, the rut depths for the worn sections that did not receive a leveling course ranged from 0.1 to 1.05 in. Rut depths generally ranged from ¼ to ½ in. on Route 64. The surface texture of the worn and leveled sections was evaluated visually. All of the surfaces were categorized into one of the following five categories:

- Category 1: flushed asphalt surface;
- Category 2: smooth, nonporous surface;
- Category 3: slightly porous, oxidized surface;
- Category 4: slightly pocked, porous, and oxidized surface; and
- Category 5: badly pocked, porous, and oxidized surface.

These are the categories listed in the PennDOT Seal Coat Design Method (*7*).

The emulsion and aggregate application rates for all surfaces were determined using the procedure described in PennDOT Bulletin No. 27 (*7*). The PennDOT procedure uses the existing pavement condition, spread modulus (D_{50}) of the aggregate, ADT, and absorption capacity of the aggregate as the variables necessary to calculate the application rates. Aggregate whip-off for this project was assumed to be 10 percent. A summary of the seal-coat designs used in this project is presented in Table 3.

DOCUMENTATION OF CONSTRUCTION ACTIVITIES

During the construction at the Pavement Durability Research Facility and Route 64, PTI personnel documented the following activities:

- Emulsion application rate;
- Aggregate application rate;
- Quantity of whip-off aggregate;
- Environmental conditions before, during, and after construction (including air temperature, pavement temperature, relative humidity, cloud cover, and wind conditions);
- Emulsion application temperatures;
- Time between emulsion and aggregate application;
- Time between aggregate application and rolling;
- Number of roller passes; and
- Time between rolling and application of traffic.

All construction activities and equipment calibration were under the control of PennDOT personnel. No attempt was made to alter the normal construction techniques, and, to the maximum extent possible, the experimental aspects of the project were designed to minimize any disturbance of normal construction procedures. Obviously, a large amount of data was obtained, making it impossible to report even a summary of the measurements herein. Complete documentation of the various methods used to obtain the measurements, as well as the measurements themselves, can be found elsewhere (*8*).

TABLE 3 SUMMARY OF SEAL-COAT DESIGN

Experiment	Aggregate	Surface	Emulsion Application Rate (gal/yd^2)	Aggregate Spread Rate (lb/yd^2)
Pavement Durability Research Facility[1]		Worn ID-2	0.27 (low)	22
		New ID-2	0.35 (high)	22
	Single-sized stone[2]	Worn ID-2	0.27 (low)	20
		New ID-2	0.35 (high)	20
Route 64[3]	Graded	Worn ID-2	0.30	18
		Worn seal coat	0.30	18

[1]Determined using PennDOT design procedure and the following assumptions:

D_{50}:	0.268 in
Loose Unit Weight:	90.4 lb/ft^3
ADT:	>2,000 vehicles/day
Absorptive Aggregate:	Yes
Bitumen Type:	Emulsion
Surface Condition:	
Worn ID-2:	Category 2, smooth, nonporous surface
New ID-2 Leveling:	Category 3, lightly-pocked, porous, and oxidized surface
Whip-off:	Use 10 percent

[2]Aggregate spread rate for the single-sized stone was selected on the basis of engineering judgment.

[3]All values selected by PennDOT personnel on the basis of local experience.

PERFORMANCE INDICATORS

The following techniques were used to monitor the performance of the seal-coat test sections at regular intervals:

- Sandpatch method (ASTM E965-83): four per section in the outer wheelpath; monthly.
- Skid resistance (ASTM E274-85): five per section in the wheelpaths; monthly.
- Visual evaluations (Texas State Department of Highways and Public Transportation Method): three evaluators per section assigned an overall rating, and ratings for bleeding and aggregate retention; monthly.
- Geotextile pads: Several were placed in each test section to evaluate aggregate loss with time; method failed (textiles could not be recovered and seemed to affect performance).

A detailed explanation and evaluation of each of these techniques can be found elsewhere (*8,10*). The mean texture depth was found to give the best indication of expected seal-coat life and an excellent parameter for comparing well-constructed seal coats on a relative basis (*8,10*).

DATA ANALYSIS: PRIMARY CONSTRUCTION VARIABLE EXPERIMENT

Visual observations during 13 months of accelerated traffic at the Pavement Durability Research Facility indicated the following:

- On the basis of the general appearance of the seal-coat sections at any given time, the various seal-coat sections clearly performed differently (i.e., some sections definitely outperformed others).
- The macrotexture of all the sections decreased with time and traffic, apparently as a result of aggregate wear and embedment.
- All sections maintained adequate macrotexture and skid resistance throughout the experiment.
- Little chip loss was observed in the wheel tracks of any of the sections.
- Chip loss caused by snowplows was severe between the wheel tracks of all the sections. It should be noted that traffic was highly channelized at the Pavement Durability Research Facility so that there was no traffic between the wheel track to help set the aggregate in that area.
- The first failures at the Pavement Durability Research Facility were caused by shoving of the leveling course mixtures during hot weather. The failures were at least partially caused by a lack of bond between the leveling course and the original surface. Although some of these sections were repaired, these types of failures eventually led to the stoppage of traffic.
- No failures resulted from a complete loss of texture or skid resistance. However, some sections no doubt were close to losing skid resistance, others appeared to have excellent texture, and a number of sections were somewhere between.

As illustrated in Figure 1, the mean texture depth (MTD) measurements for all the test sections showed a consistent and similar relationship when plotted as a function of time.

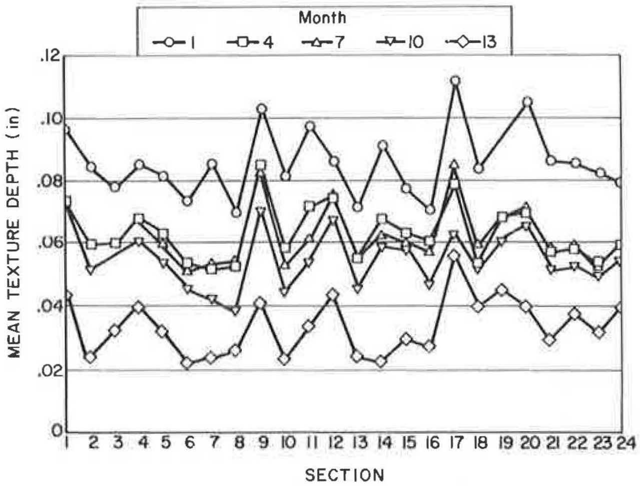

FIGURE 1 Mean texture depths at different times: primary experiment.

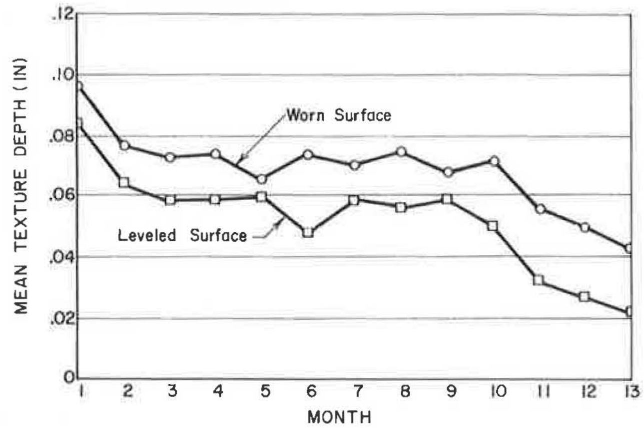

FIGURE 2 Mean texture depth as a function of time for worn and leveled surfaces, low emulsion application rate: typical.

This figure, which shows a comparison of the MTD measurements for all sections at different times, indicates that MTD dropped fairly sharply for all sections after Month 1, but after Month 4, the MTD reduced more slowly. Another significant drop in MTD was observed for all sections after Month 10. The sharp drops occurred during hotter months when the aggregate embedment rate was higher.

Because of the consistency of the MTD measurements and the significant differences observed in MTD between the different sections, a more detailed analysis of the MTD measurements was performed to evaluate the effects of the design and construction variables on seal-coat performance. Because higher MTD implies greater macrotexture, and greater retained macrotexture results in prolonged skid resistance, it appeared reasonable to use MTD as a performance criterion. This is particularly valid for the seal-coat sections in this experiment because they exhibited a minimal amount of chip loss in the wheel tracks. The analysis is presented next.

Effect of Surface Type

Analysis of the MTD measurements indicated that for the lower emulsion application rates used in this investigation, the seal coats constructed on leveled surfaces had consistently lower retained MTD than did seal coats on worn surfaces. This is illustrated in Figure 2, which shows a comparison of MTD versus time between a seal-coat section constructed on a leveling course and one constructed on a worn surface with all other factors held constant. The same trend was evident in similar comparisons for the five other pairs of sections constructed with low emulsion rates and for which the only difference was surface type. This result was expected because the low emulsion application rate was the design rate for the worn surface and considered too low for the leveled surface. Measurements obtained during construction indicated that the lower emulsion rates used in this investigation resulted in lower initial aggregate retention on the leveled surfaces than on the worn surfaces, which partly explains the lower MTDs.

Comparisons made between seal-coat sections on leveled and worn surfaces but constructed using high emulsion application rates indicated that there was no clear difference in retained MTD. Approximately the same amount of aggregate was retained on both surfaces when the higher emulsion rate was used.

The highest retained MTDs were obtained on worn surfaces. In other words, the retained MTD was generally higher on worn surfaces, even when the initial chip retention was comparable for both types of surfaces. This is probably because leveled surfaces are softer than the older worn surfaces and, therefore, allow more embedment and reorientation of the aggregate.

These results seem to indicate that a leveling course should not be applied before a seal coat unless it is absolutely necessary to overcome a severe rutting problem. Leveling courses require additional emulsion for adequate chip retention and, on the basis of the results obtained, do not appear to offer any benefits in terms of seal-coat performance.

Effect of Emulsion Application Rate

This variable appeared to control the retained mean texture depth for both the worn and the leveled surfaces for the range of emulsion rates used in this investigation. In the case of worn surfaces, even the lowest emulsion application rates used were sufficient for adequate initial chip retention. Additional emulsion on the worn surfaces served only to reduce the macrotexture of the seal-coat surface. For leveled surfaces, it was found that the amount of aggregate retained initially was related to the emulsion application rate used. The lower emulsion application rates were not enough for adequate initial chip retention on some of the leveled surfaces.

Figure 3 shows a comparison of MTD versus time between two sections constructed on worn surfaces: one with a high emulsion application rate, the other with a low application rate. All other factors were constant for these sections. The figure shows that the section with the lower emulsion application rate had the higher retained MTD. Similar comparisons between seal coats on worn surfaces and for which the only difference was the emulsion application rate showed the same trend. Statistical analyses performed on MTD measurements on worn surfaces not only confirmed that emulsion application rate had a significant effect on retained MTD, but also in-

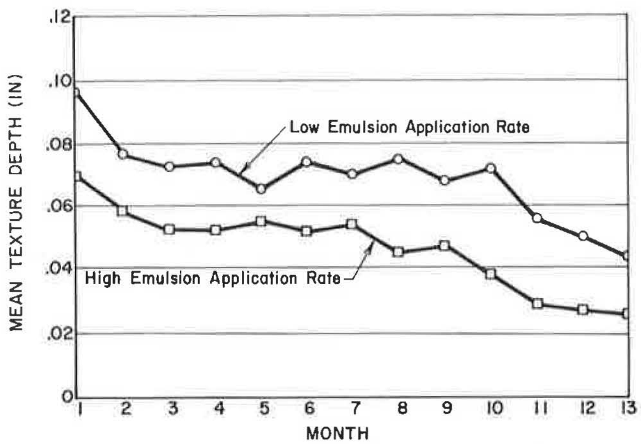

FIGURE 3 Mean texture depth as a function of time for low and high emulsion rates: worn surfaces, Month 13.

dicated that the effect of this factor overwhelmed the effect of all other factors in this experiment. Regression analyses were performed using MTD as the dependent variable and the following factors as independent variables:

- Emulsion application rate (measured),
- Number of roller passes,
- Traffic control (actual time after compaction before traffic was allowed on the seal coats),
- Weather during construction,
- Rut depth of the existing surface, and
- Interactions between these factors.

A forward stepwise multilineal regression procedure was used to analyze the MTD data for each month. For each month, the analyses indicated that the measured emulsion application rate was the only factor necessary to account for the observed differences in retained MTD between the seal-coat sections constructed on worn surfaces. The following regression model was obtained by analyzing the MTD measurements from Month 8:

$$\text{MTD} = 0.096 - 0.125^{*}\text{EAR} \qquad R^2 = 0.71 \qquad (1)$$

where MTD is the mean texture depth (in.) and EAR is the measured emulsion application rate (gal/yd^2).

A better model was not obtained, even when other factors were included. Apparently, for the range of emulsion application rates applied on the existing surfaces (0.23 to 0.41 gal/yd^2) in this investigation, the effect of emulsion application rate overwhelmed the effects of all other factors.

This finding appears to indicate that the lower emulsion application rates were the most appropriate for the worn surfaces tested. The lower rates resulted in adequate chip retention and the highest levels of retained MTD. It is unclear whether emulsion application rates lower than those used would be more appropriate for these surfaces. Because the lower emulsion application rate used in this investigation corresponded to the design emulsion rate for the existing surface (according to PennDOT's design procedure), this finding also indicates that there appears to be no evidence to change the existing design procedures for the worn surfaces and the aggregate tested in this investigation.

A clear relationship was not found between the emulsion application rate and the retained MTD on leveled surfaces. However, separate regressions performed using aggregate retained as the dependent variable indicated that the amount of aggregate initially retained on the leveled surfaces was related to the emulsion application rate. The amount of aggregate retained initially as determined from measurements during construction was used as the dependent variable, and the following factors were included as independent variables in the regression:

- Emulsion application rate (measured),
- Number of roller passes,
- Weather during construction,
- Rut depth of the existing surface, and
- Interactions between these factors.

A forward stepwise multilineal regression analysis was used, and the following regression model was obtained:

$$\text{AGG} = 10.8 + 21.1^{*}\text{EAR} + 2.0\,TC3 \qquad R^2 = 0.72 \qquad (2)$$

where

AGG = lb/yd^2 of aggregate retained on the leveled surface;
EAR = measured emulsion application rate (gal/yd^2); and
*TC*3 = a dummy variable corresponding to the hotter, dryer, and windier construction day.

For the range of emulsion application rates used on the leveled surfaces (0.23 to 0.41 gal/yd^2), the lower emulsion rates apparently were not sufficient for adequate initial chip retention. Greater initial chip retention should result in greater retained MTD and improved long-term performance. Therefore, the higher emulsion rates used in this investigation apparently were most appropriate for the leveled surfaces. Because, according to PennDOT's design procedure, the higher emulsion application rate used corresponded to the design emulsion rate for the rougher, leveled surface; this finding also indicates that no evidence to change the existing design procedure for the leveled surfaces and the aggregate tested in this investigation is apparent.

Other Factors

The number of roller passes seemed to have no effect on the retained MTD of the seal coats constructed on either worn or leveled surfaces. No relationships were found, either from basic plots or from regression analyses, between the number of roller passes and the retained MTD of the seal-coat sections.

The level of traffic control also seemed to have no effect on the retained MTD of the seal-coat sections constructed on either worn or leveled surfaces. Again no relationships were found, either from basic plots or from regression analyses, between traffic control and the retained MTD of the seal-coat sections.

Of the other factors considered in the analysis (weather, rut depth, aggregate retained, and in-place aggregate gradation), none were found to have a significant effect on the retained MTD of the seal coats on existing surfaces or leveled surfaces. As mentioned earlier, the amount of aggregate retained on the leveled surfaces was found to be related to weather and emulsion rate. Apparently, a greater amount of aggregate was retained on the hotter, dryer, windier construction day. This is logical, because these conditions are conducive to the emulsion breaking faster. This would also appear to indicate that aggregate retention may be reduced in areas that are shaded.

DATA ANALYSIS: SECONDARY MATERIAL VARIABLE EXPERIMENT

Both the visual ratings and the measurements of mean texture depth reflected the lack of variation in performance among the sections in the modifier experiment. After 13 months of accelerated traffic the visual evaluators observed little difference in chip retention or bleeding and flushing among these sections. Also, the difference between the sections with the highest and lowest retained MTD after 13 months was only 0.017 in., compared with a difference of 0.034 in. observed in the primary experiment.

Statistical analyses performed on the retained MTD after 13 months of traffic confirmed that for each of the four modifiers, no significant difference existed between the MTD of the modified section and the MTD of its corresponding control section. *T*-tests were performed using an error term determined from the control sections.

In general, all of the MTD versus time relationships for the modified sections closely resembled those observed for the sections in the primary experiment. This may indicate that the pattern of aggregate wear and embedment for the modified sections was the same as for the unmodified sections. This also appears to indicate that the modifiers used in this investigation did not help to prevent embedment during hot weather.

On the basis of retained MTD measurements, no evidence is apparent to indicate that the single-sized stone sections outperformed comparable sections constructed with graded aggregate. Figure 4 shows a comparison of MTD versus time between comparable single-sized stone and graded aggregate sections constructed on worn surfaces. There is no discernible difference between the two. The results shown for the graded aggregate sections in Figure 4 were the average of the MTD measurements for sections 1 and 4 from the primary experiment.

DATA ANALYSIS: ROUTE 64 EXPERIMENT

The results obtained on Route 64 confirmed the findings of the experiments at the Pavement Durability Research Facility. Analyses of MTD measurements indicated that roller passes had no effect on retained MTD. Comparisons of MTD versus time among sections constructed using one and two roller passes and for which all other factors were constant clearly indicated that roller passes had no effect on retained MTD.

Finally, the relationship of MTD versus time for the modified and control sections on Route 64 exhibited the same trend that was observed for similar sections at the Pavement Durability Research Facility. This again indicates that the

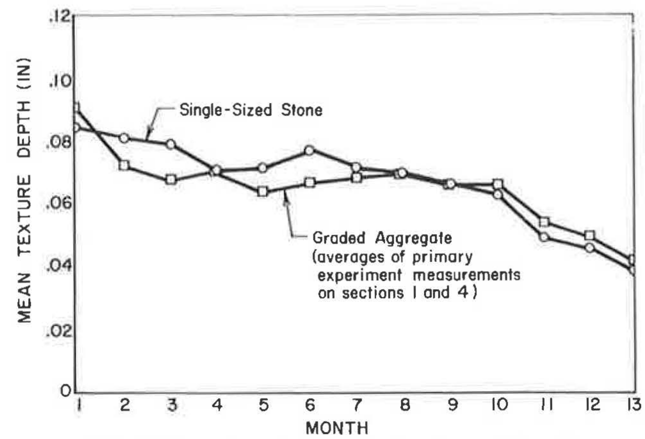

FIGURE 4 Mean texture depth as a function of time for single-sized stone section and control sections on worn surfaces.

modifiers were unsuccessful in preventing the embedment during hot weather.

SUMMARY AND CONCLUSIONS

On the basis of the findings of this investigation, a number of conclusions are presented relating to each of the different phases of a seal-coat operation.

Surface Preparation

Worn surfaces should not be leveled before applying a seal coat unless rutting or surface roughness or both are so severe that they cause a safety or maintenance problem.

For the materials and surfaces tested in this investigation, it was found that rut depths up to 1 in. had no influence on the constructibility or performance of seal coats. Also, seal coats constructed on worn surfaces resulted in higher retained mean texture depths and longer expected life.

Materials Selection and Specifications

1. Good seal coats can be produced using aggregates and emulsions that meet PennDOT's existing specification (⅜-in. maximum size graded aggregate) if emulsion application rates and aggregate application rates are closely controlled in the field.
2. For the aggregate used in this investigation, there seemed to be no advantage in using single-size stone over the graded aggregate.
3. On the basis of the results of this study, polymer-modified emulsions are not warranted. However, their consideration should not be discontinued, particularly in which cases in which the need for early chip retention and conditions such as intersections and corners are encountered.

Design

PennDOT's design charts give reasonable estimates of the most appropriate emulsion application rates for the graded aggregate tested in this investigation.

Construction

1. When 8-ton pneumatic rollers are used, no more than one roller pass needs to be specified for proper seal-coat compaction.
2. No more than 2 hr of traffic control needs to be specified after construction before a seal coat is open to traffic.
3. It was unclear whether traffic control of less than 2 hr can be allowed. Therefore, for lack of more detailed information, 2-hr traffic control should be the minimum allowed before opening a seal coat to traffic.

Quality Control

Emulsion application rate and amount of aggregate retained were found to be the most important factors governing seal-coat performance. Therefore, both the distributor and the chip spreader must be properly calibrated.

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