Bituminous Seal Coats: Design, Performance Measurements, and Performance Prediction

REYNALDO ROQUE, MATTHEW THOMPSON, AND DAVID ANDERSON

A field study was conducted at the Pennsylvania Transportation Institute's Pavement Durability Research Facility at Pennsylvania State University to determine the effects of specific construction, traffic, and material variables on the performance of bituminous seal coats. As part of the study, the adequacy of existing seal-coat design procedures, quality control procedures, and seal-coat performance measuring techniques was evaluated. The focus of this paper is on the latter evaluation; the effects of the other variables are reported elsewhere. The evaluations were based on actual field measurements and led to numerous recommendations for improvements in seal-coat design methods, equipment calibration, measurement and evaluation of seal-coat performance, prediction of seal-coat life, and the appropriate use of seal coats as a maintenance technique. The recommendations are reported herein. Finally, a definitive pattern of seal-coat macrotexture degradation was identified under this closely monitored field experiment. This finding was used to develop a prediction model for seal-coat life. Aggregate wear rates and embedment rates were measured on two surfaces under closely monitored traffic loading conditions. The wear and embedment rates were used to illustrate the potential of the seal-coat-life prediction model to evaluate the effects of different variables on expected seal-coat life. On the basis of the deficiencies observed in the existing design procedures, updated design charts that use more objective methods of evaluating the existing pavement surface are proposed, as are potential methods for rating the surface.

Seal coats are one of the most efficient and cost-effective methods available to state highway departments to rehabilitate and increase the skid resistance of highway pavements (*1*). However, results of surveys in Pennsylvania and elsewhere indicate that premature failure of seal coats is a common occurrence (*2*). These failures may be caused by improper design and construction procedures, substandard materials, or simply use of seal coats in cases in which some other form of maintenance may be more suitable.

Comparisons of aggregate and emulsion application rates predicted by different seal-coat design procedures indicate that a great deal of uncertainty is involved in seal-coat design. Roque et al. (*2*) showed that, for the same surface and aggregate, the emulsion application rate predicted by seven design procedures ranged from 0.19 to 0.30 gal/yd^2. These comparisons appear to indicate that much improvement can be made in categorizing surface hardness and texture and in including wear and embedment characteristics of the aggregate in the design process.

Pennsylvania Transportation Institute, Pennsylvania State University, Research Building B, University Park, Pa. 16802.

Although a great deal of research has been devoted to analyzing the factors that affect seal-coat performance and seal-coat design procedures, no one has attempted to develop a model to predict seal-coat life. Only Marais attempted to incorporate the concept of a design life into a design process (*3*). However, Marais did not present a model to predict seal-coat life using known or measured properties of the materials and pavement surfaces. Most highway agencies predict the performance life of a seal coat on the basis of previous experience. Average seal-coat life expectancies range from 3 to 10 years (*4*). These averages are used to establish statewide maintenance budgets but are of little predictive value for individual projects. For example, McLeod and Nagi reported on seal coats performing well after 10 to 15 years, whereas others failed after only 1 or 2 years (*5,6*). If highway engineers are to make informed decisions about seal-coat maintenance within the framework of pavement management systems, then prediction models for seal-coat life must be developed.

DESCRIPTION, MATERIALS, AND COLLECTION OF FIELD DATA

Experiment Description

The following four variables were included in the experiment:

1. Pavement condition: worn ID-2 or new ID-2 leveling;
2. Emulsion rate: high or low;
3. Number of roller passes: 1 or 3; and
4. Traffic control (delay before application of traffic): 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 the Pennsylvania Department of Transportation (PennDOT); the maximum aggregate size is ⅜-in.

Traffic

Traffic at the Pavement Durability Research Facility was started August 8, 1988, and continued through August 18, 1988. Traffic consisted of a tractor pulling two single-axle trailers loaded to the legal axle limit of 22,400 lb per axle. Two two-person crews operated the truck for approximately 16 hr a day. A total of 73,400 truck passes was applied during the monitoring period.

Materials

A single aggregate source and emulsion were used. The aggregate was a heterogeneous, siliceous, glacial gravel produced at the Fairfield Township operation of Lycoming Silica Sand Company. The aggregate met the grading requirements for a Pennsylvania IB stone (AASHTO 8) that is to be used for seal-coat work (*7*). The percentage of material passing the No. 200 sieve was less than 1 percent. This aggregate met all other PennDOT specification criteria. Data for the aggregate gradation (sieve analysis) were as follows:

	Percent Passing	
Sieve Size	*IB*	*Single-Sized*
½ in.	100	100
⅜ in.	89	92
No. 4	21	8
No. 8	8	4
No. 16	4	3.5
No. 30	4	not applicable
No. 200	1	1

Data for the hydrometer analysis (the percent finer than the given size expressed as a percent of the total aggregate) were as follows: .025 mm, .55; .008 mm, .29; .001 mm, .13. Additional data were as follows: 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.

A standard E-3 (ASTM CRS-2) emulsion was used in the construction of all test sections. The properties of the base asphalt cement used to manufacture the E-3 emulsion satisfied the requirements for an AC-10 asphalt cement. Routine tests performed on the emulsified asphalt indicated that all PennDOT specifications were met. An extensive series of conventional and nonconventional tests was performed on both the aggregate and the emulsion used in the project. The results of these tests can be found elsewhere (*2*).

Preconstruction Evaluation

The rut depths and surface texture of the pavement sections were evaluated before seal-coat construction. Measured rut depths ranged from 0.1 to 1.05 in. for the sections tested. The surface texture of the worn and leveled sections was evaluated visually. All of the surfaces were categorized into one of the five categories listed in the PennDOT Seal Coat Design Method (*7*). For design purposes, the worn ID-2 wearing surfaces were classified as smooth, nonporous surfaces (Category 2). The leveled surfaces, though not oxidized, were classified as slightly pocked, porous, and oxidized surfaces (Category 4).

Documentation of Construction Activities

During construction, Pennsylvania Transportation Institute 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.

The emulsion application rate was determined with two different methods: the Standard Recommended Practice for Determining Application Rate of Bituminous Distributors (ASTM D 2995) and a procedure whereby fabric patches were placed on the pavement. The patch method, though simple and rapid, has not been standardized. The procedure was performed as follows:

1. A 2- × 2-ft, preweighed geotextile patch was placed on the pavement surface before the application of the emulsion. The fabric—4 oz/yd^2 nonwoven needle-punched polypropylene (Petromat L17540)—was nailed to the pavement at its corners with ½-in. roofing nails.
2. Immediately after the application of the emulsion but before the spreading of the aggregate, the fabric was carefully removed and placed in a preweighed plastic trash bag.
3. The trash bag containing the emulsion-soaked fabric was returned to the laboratory, opened, and placed in an oven at 140°F (± 5°F) for 24 to 48 hr to evaporate the water.
4. The asphalt-soaked fabric and the trash bag were weighed, and the quantity of emulsion in gallons per square yard was calculated using the water content of the emulsion and the specific gravity of the emulsion.

The Standard Recommended Practice for Determining Application Rate of Bituminous Distributors (ASTM D 2995) can be used to measure the transverse uniformity of the emulsion application rate, but it is more tedious to perform. Neither the ASTM method nor the geotextile patch procedure is suitable as a quality control test because of the turnaround time required to obtain the test results.

All measurements obtained with these methods on each of the seal-coat sections tested can be found elsewhere (*2*). On the basis of detailed statistical analyses performed on the emulsion rate measurements obtained, replicate samples appear to be necessary to obtain reliable results from either of these methods. The geotextile method described herein was found to be much less cumbersome and is therefore recommended over the cotton pad method. The geotextile method was determined to be sufficiently repeatable for use as a routine test procedure for checking emulsion application rates as long as three or more determinations are made for each test (*2*).

Aggregate Application Rate and Whip-Off

The aggregate application rate was determined in triplicate by the following method:

1. A 22- × 22-in. pan was placed between the wheelpaths of the pavement immediately after the emulsion was applied.
2. After the chip spreader passed over the pan, the pan was moved to the side of the pavement.
3. The collected aggregate was transferred to a preweighed bucket and dried in an oven at 140°F (± 5°F) for 24 hr.
4. The dried aggregate was weighed, and the aggregate application rate in pounds per square yard was calculated.

The aggregate not captured by the emulsion film (and susceptible to whip-off under traffic) also was measured for each test section by the following method:

1. The test was conducted approximately 20 to 50 min after the aggregate was rolled, when the bulk of the water in the emulsion had evaporated.
2. A 1-yd^2 template was placed between the wheelpaths of the test section.
3. All loose chips within the template area were collected by carefully brooming the pavement surface and were placed in a plastic bag for transport to the laboratory.
4. The aggregate was dried in an oven at 140°F (± 5°F) for 24 hr and weighed, and the aggregate whip-off in pounds per square yard was calculated.

The actual measurements of aggregate application rate and estimated whip-off can be found elsewhere, along with a detailed statistical analysis of these measurements (*2*). The results indicated that the variability between target and applied aggregate rates was significant. Although the variability is not good from the standpoint of construction, it did allow the research team to evaluate the effect of amount and gradation of aggregate retained on seal-coat performance and the reasonableness of the assumption of 10 percent whip-off for design purposes. The measurement techniques themselves were found to be relatively simple and accurate and are recommended as routine test procedures for checking aggregate application rates.

DESIGN OF SEAL COATS

The emulsion and aggregate application rates were determined using the procedure described in PennDOT Bulletin 27 (*7*). The PennDOT procedure uses the existing pavement condition, spread modulus (D_{50}) of the aggregate, average daily traffic (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. The design for the Pavement Durability Research Facility was based on the following data:

- 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) and
  - New ID-2 leveling: Category 3 (lightly-pocked, porous, and oxidized surface); and
- Whip-off: 10 percent.

On the basis of these data, the following emulsion application rates were determined for the surfaces at the Pavement Durability Research Facility:

Surface	*Emulsion Application Rate (gal/yd^2)*
Worn ID-2	0.27
New ID-2 leveling course	0.35

EVALUATION OF PERFORMANCE MEASURING TECHNIQUES

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

- Sandpatch method,
- Skid resistance,
- Visual evaluations,
- Stereophotographs, and
- Geotextiles.

Table 1 includes a summary of the parameters that were obtained and the frequency, number, and location of measurement for each of these techniques. The table also presents a summary of the advantages and disadvantages of each technique in evaluating the performance of seal coats as determined from this project.

For this experiment, the mean texture depth (MTD) provided the most effective indication of seal-coat performance. This parameter proved to be sensitive and consistent in indicating the relative performance of the sections over time. This point is illustrated in Figure 1, which shows MTD as a function of time for three test sections: one with low MTD, one with intermediate MTD, and one with high MTD. Figure 2 shows that a similar trend in MTD over time was observed for all 24 test sections. The figure shows the MTD over time for all the test sections at specific times during the experiment. These consistent patterns were not detected by any of the other measuring techniques. The visual ratings were clearly affected by lighting conditions and other external factors so that no consistent pattern was observed over time or between evaluators. The skid resistance test was simply not sensitive to the texture changes taking place during the course of the experiment. A more detailed comparison of the measurements can be found elsewhere (*2,8*).

PREDICTION OF SEAL-COAT LIFE

The detailed measurements obtained during this experiment indicate that it may be possible to develop a model to estimate the life of seal coats that are well constructed and do not suffer from excessive chip loss. As shown in Figures 1 and 2,

TABLE 1 EVALUATION OF PERFORMANCE MEASUREMENTS FOR SEAL COATS

Technique	Parameter Obtained	Frequency	Number Per Section (location)	Advantages	Disadvantages	Remarks
Sand Patch	Mean Texture Depth (MTD)	Monthly	4 (outer wheel path)	Objective, sensitive	Small test area; distress mode not identified	May become less sensitive as macrotexture is reduced.
Skid Resistance	Skid Number (SN)	Monthly	5 (wheel path)	Covers entire section length, microtexture and microtexture may be evaluated	Lacks sensitivity early, affected by temperature and contamination, distress mode not identified	Becomes more sensitive as macrotexture is reduced.
Visual Examination	Three performance ratings: overall; bleeding; aggregate retention	Monthly	3 Evaluators (entire section)	Covers entire section; identifies failure mode	Subjective, lacks sensitivity, affected by lighting and environment	Unsuitable for ranking the sections or for detailed analysis.
Stereophotos	None	Monthly	1 (outer wheel path)	Visual record of changes with time at one location	Small test area.	Unsuitable for detailed analysis, since no parameter is obtained.
Geotextiles	None	---	---	---	Appear to affect performance	Did not work (could not be recovered from sections

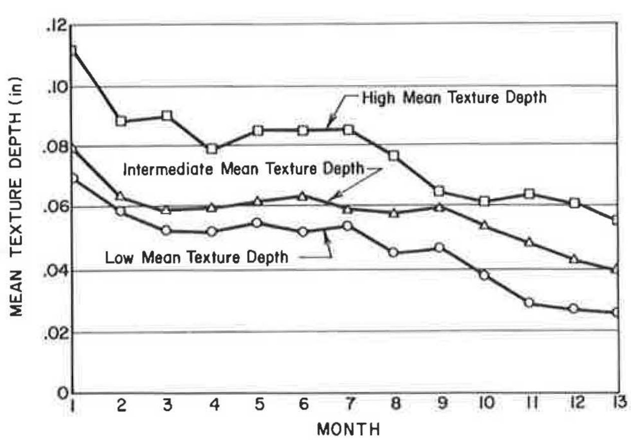

FIGURE 1 MTD as a function of time for low, intermediate, and high MTD sections.

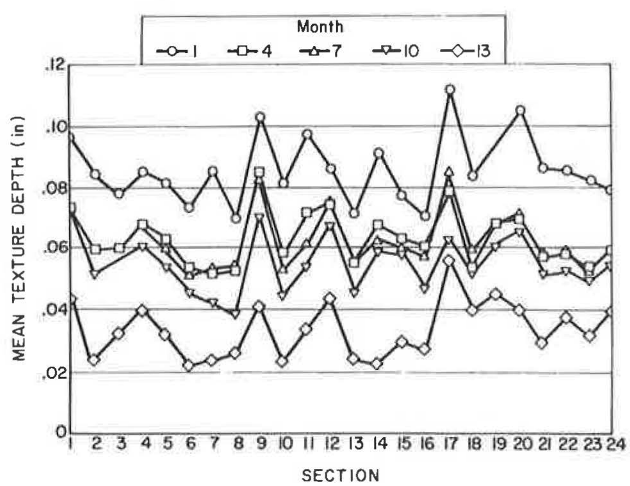

FIGURE 2 MTD at different times.

a consistent pattern was observed for the reduction in the MTD over time for all the test sections. It was found that during the warm months, the rate of reduction in MTD was greater than in the cool months. A generalized version of the pattern is illustrated in Figure 3, which shows MTD as a function of time or wheel passes. It was concluded that during cooler months, the underlying surface is sufficiently stiff to prevent aggregate embedment, so that the reduction in MTD may be attributed solely to aggregate wear. During warmer months, the underlying pavement surface stiffness decreases, thereby allowing aggregate embedment. It is assumed that the rate of wear is the same during cool and warm months.

Based on these findings, a simple model was developed to estimate seal-coat life by predicting the number of design wheel passes it will take for a seal coat to reach some terminal MTD. The model essentially predicts the seal coat's MTD as a function of time or wheel passes by using the equation shown

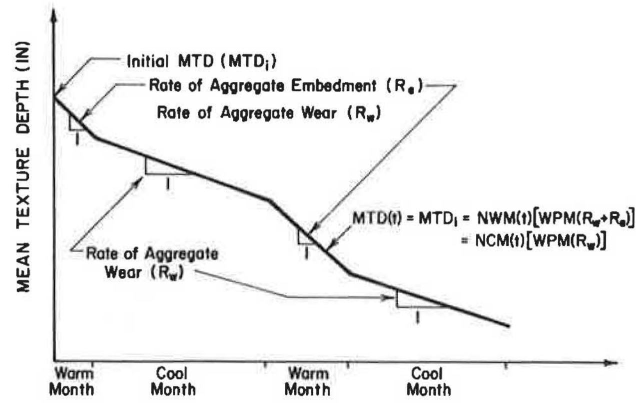

FIGURE 3 MTD as a function of time or wheel passes.

in Figure 3. The basic elements needed to estimate seal-coat life are as follows:

- The wear rate of the aggregate under traffic loading,
- The stiffness characteristics of the underlying surface as related to the aggregate embedment rate (primarily at warmer temperatures), and
- An estimate of traffic volume and distribution.

Using these elements, it is proposed that the following equation can be used to estimate seal-coat service life:

$$\mathrm{MTD}(t) = \mathrm{MTD}_i - \mathrm{NWM}(t)\,[\mathrm{WPM}(R_w + R_e)] - \mathrm{NCM}(t)\,[\mathrm{WPM}(R_w)] \quad (1)$$

where

- $\mathrm{MTD}(t)$ = Mean texture depth (in.) at time t,
- MTD_i = Initial mean texture (in.),
- NWM = Number of warm months,
- WPM = Number of loaded wheel passes per month,
- R_w = Rate of wear during warm and cool months (in./20,000 wheel passes),
- NCM = Number of cool months, and
- R_e = Rate of embedment during the first three years of warm months (in./20,000 wheel passes). (Note that $R_e = 0$ for $t > 36$ months.)

This equation is based on several assumptions. First, the initial MTD must be measured or estimated. MTD measurements can be obtained after construction, but it is recommended that the measurement be taken 1 month after construction. If MTD measurements are not available, the initial MTD can be estimated as a percentage of the average least dimension (ALD) of the seal-coat aggregate. McLeod's design procedure assumes that the binder will have a height equal to 50 to 70 percent of the ALD (*5*). Therefore, the initial MTD will be 30 to 50 percent of the ALD. An average value of 40 percent can be used. In this model, only truck tires (80 to 100 psi) are assumed to produce aggregate wear and embedment.

Finally, it is assumed in this equation that embedment is a gradual process and is considered to reach an equilibrium after 3 years (*3*). For seal coats placed on asphalt concrete surfaces, it appears that the aggregate will cease to embed at some point. No one has attempted to quantify the amount of time or level of embedment at which embedment will no longer continue. Marais suggested that 3 years is an appropriate time period but noted that this time is affected by traffic volume. The MTD data from this experiment did not indicate that the seal coats reached an embedment equilibrium point. Thirteen months of accelerated traffic were applied to the test sections.

Determination of Aggregate Wear and Embedment Rates

Aggregate wear and embedment rates were measured under closely controlled field conditions at the Pavement Durability Research Facility. The rates were obtained for one aggregate on the two surfaces used in this investigation by converting the MTD and traffic data into the units required by Equation 1. The wear rate was computed as the loss in MTD per wheel pass during cool months, whereas the embedment rate was computed as the loss in MTD per wheel pass during warm months minus the calculated wear rate. The wear and embedment rates were determined for each surface type by finding R_w and R_e as defined in Figure 3, by using regression analysis on actual plots of MTD versus wheel passes for each traffic section. The following values were obtained:

- Worn ID-2: wear rate = 0.0080 in. (MTD) per 20,000 wheel passes; embedment rate = 0.0050 in. (MTD) per 20,000 wheel passes.
- Leveled ID-2: wear rate = 0.0080 in. (MTD) per 20,000 wheel passes; embedment rate = 0.0052 in. (MTD) per 20,000 wheel passes.

Additional details on the computations can be found in work by Thompson (*8*). As expected, the wear rate was identical for both surfaces because the same aggregate was used for both. The embedment rates were also nearly equal, which indicates that both surfaces had about the same stiffness.

Analyses Using the Model

A computer program based on Equation 1 was developed on spreadsheet software to estimate seal-coat life. A simplified flowchart of the program is shown in Figure 4. The following input is required:

- Highway ADT, percentage of trucks, and number of axles per truck. The program uses the three input parameters to determine the number of wheel passes per month (WPM).
- Initial MTD after construction. This value can be measured or estimated.
- The date of construction. This establishes a starting point from which the number of warm and cool months can be determined.
- The rate of MTD reduction resulting from aggregate wear (occurs during both warm and cool months), and the rate of MTD reduction resulting from aggregate embedment (occurs during warm months only).
- MTD failure criteria. This is the value of MTD that the user defines as seal-coat failure (MTD_f).

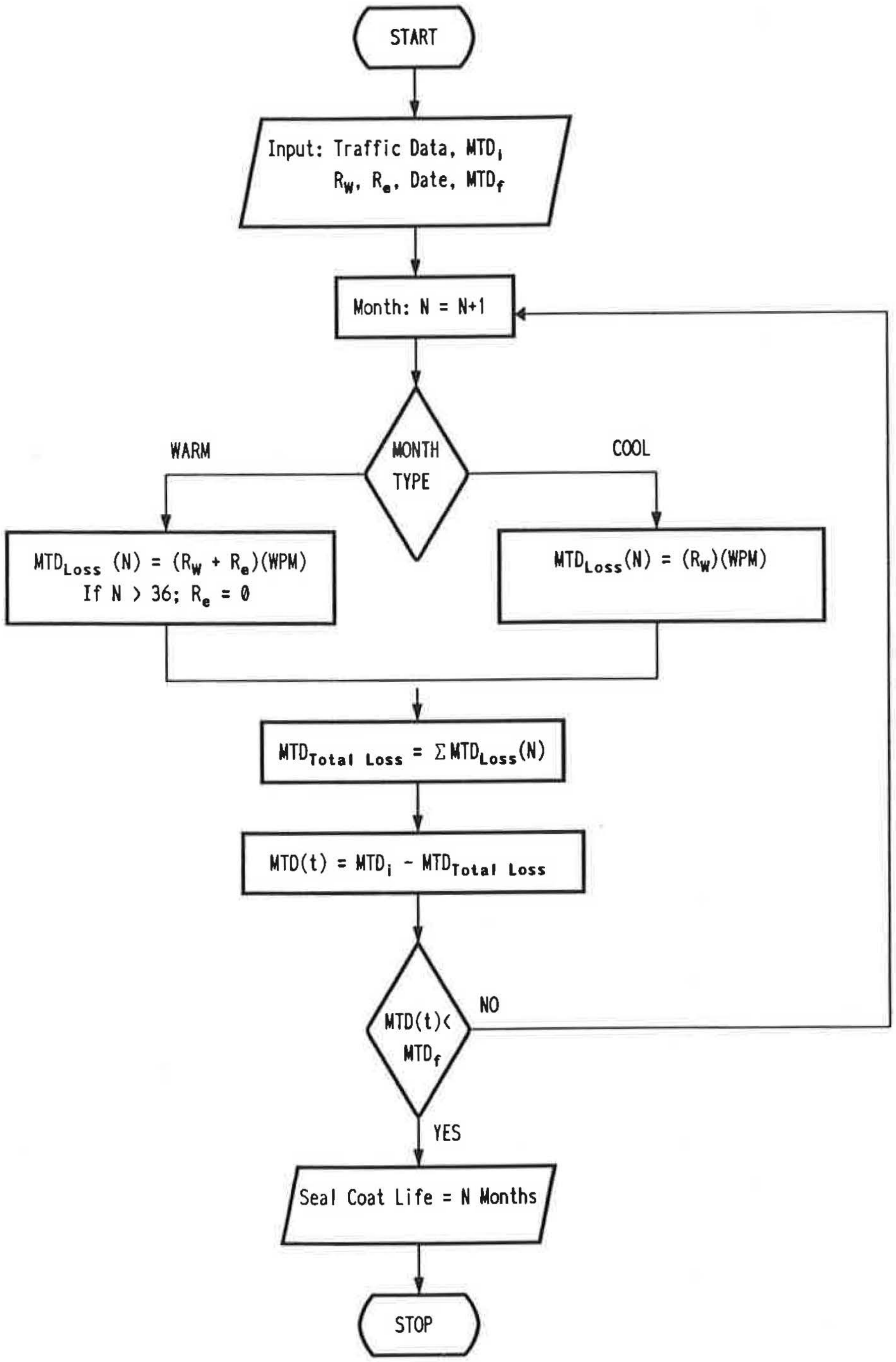

FIGURE 4 Flow chart of computer program to predict seal-coat life.

The program uses the data above to estimate the amount of MTD reduction each month. It then sums these reductions in MTD until the remaining MTD is less than the failure criteria. The program counts the number of iterations required to reach the failure criteria and uses that number to determine the following information:

- The predicted number of wheel passes to failure,
- The predicted life of the seal coat in months, and
- The predicted date of failure on the basis of the construction date.

Although not validated, this program provides a means by which to predict differences in expected seal-coat life caused by variations in aggregate characteristics, underlying surface stiffness, and emulsion application rates. Sabey recommended an MTD failure criterion of 0.025 in. as the texture depth below which a seal coat will no longer have adequate skid resistance (*9*). As mentioned earlier, if measured values are not available, the initial MTD of a well-constructed seal coat can be estimated as approximately 40 percent of the average least dimension of the aggregate used. Aggregate wear rates can be measured as was done in this investigation and eventually determined from relationships to laboratory tests such as the ones proposed by Marais and shown in Table 2 (*3*). Similarly, aggregate embedment rates would need to be measured as in this investigation and eventually determined from relationships to surface hardness. The results of this investigation indicated that the embedment rates for the two surfaces tested were not significantly different.

Several analyses were performed to illustrate the potential of the model. An ADT of 2,000 with 10 percent trucks was assumed with an initial MTD of 0.085 in. and an August construction date. In one analysis, the effect of aggregate wear rate was compared. The embedment rates measured for the field test sections in this experiment were used for the analysis. The wear rate of the aggregate in this experiment was 0.0008 in. per 20,000 wheel passes. Its Los Angeles abrasion loss was 30 percent. Using Marais's relationships (Table 2), a wear rate of 0.0006 in. per 20,000 wheel passes was determined. Using the model, a difference in expected life of approximately 1 year was computed. Similar comparisons can be made for the effect of underlying surface stiffness, emulsion application rate, and traffic (*8*).

At present, of course, the accuracy of the predictions is uncertain. Therefore, the model is simply proposed as a method to objectively evaluate the effects of different factors on a relative basis. Only systematic measurements and experience will validate the model.

ADJUSTMENTS TO EXISTING DESIGN CHARTS

Most existing design procedures compute the emulsion application rate by simply using a visual evaluation of the surface. An evaluation of visual ratings as performed in this investigation indicated that the rating obtained by two different evaluators, or even by the same evaluator on two different days, may be very different. Also, visual ratings do not give a true indication of the surface hardness. Given the importance of determining proper emulsion application rates in producing adequate seal coats, a better, more objective method of rating the existing surface is needed.

The sandpatch test, which measures MTD, was found to be reliable and consistent for measuring surface texture. It is therefore recommended to obtain an objective measure of the texture of the pavement from which adjustments in the amount of emulsion required to fill the voids in the existing pavement can be made. McLeod's binder adjustment factors for surface texture were used to determine the amount of emulsion required for a known change in texture (*10*). A conversion factor of 1 gal/yd^2 = 0.20 in (MTD) was determined. This conversion factor was used to convert PennDOT's existing visual classification to MTD measurements, as shown below.

- Category 1 (flushed asphalt surface):
  - McLeod's Adjustment Factor = −0.06 gal/yd^2;
  - Calculated MTD = not applicable.
- Category 2 (smooth, nonporous surface):
  - McLeod's Adjustment Factor = 0.00 gal/yd^2;
  - Calculated MTD = 0.000 in.
- Category 3 (slightly porous, oxidized surface):
  - McLeod's Adjustment Factor = 0.03 gal/yd^2;
  - Calculated MTD = 0.006 in.
- Category 4 (slightly pocked, porous, and oxidized surface):
  - McLeod's Adjustment Factor = 0.06 gal/yd^2;
  - Calculated MTD = 0.012 in.
- Category 5 (badly pocked, porous, and oxidized surface):
  - McLeod's Adjustment Factor = 0.09 gal/yd^2;
  - Calculated MTD = 0.018 in.

Thus, if MTD measurements of the existing surface are obtained, it is possible to enter the design chart by using the equivalencies shown above.

Adjustments for surface stiffness would still have to be incorporated. This would require more work to relate surface hardness measurements (as described earlier) to the amount of aggregate embedment. However, the authors feel that the establishment of such relationships is well worth the effort because it would take much of the guesswork out of seal-coat design and construction and would eventually provide the capability to obtain better estimates of seal-coat life. A design example as it might be performed with the proposed measurements can be found elsewhere (*8*).

TABLE 2 ESTIMATED DEGRADATION AND WEAR UNDER CONSTRUCTION ROLLING AND TRAFFIC (10-YEAR LIFE) (*3*)

Los Angeles Abrasion Value	Degradation and wear of stone mat (mm x 10^{-2})									
	Equivalent traffic (vpd/lane)									
% Loss	>4,000	4,000	3,000	2,000	1,000	800	600	400	200	100
34 - 27	100	92	86	78	66	66	58	52	44	37
26 - 22	90	86	80	72	60	58	54	48	40	34
21 - 15	80	78	74	68	56	54	50	46	38	32
14 - 10	75	72	68	62	52	48	46	42	36	30
9 - 4	70	68	62	56	48	46	42	38	32	28

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the findings of this investigation, several conclusions were drawn related to different phases of a seal-coat operation.

Given that emulsion and aggregate application rates were found to be one of the most critical factors governing the performance of a seal coat (*2*), both the distributor and the chip spreader must be properly calibrated. The geotextile method used in this investigation and described herein was determined to be sufficiently repeatable for use as a routine test procedure for checking emulsion application rates as long as three or more determinations are made for each test (*2*). Use of a 1-yd^2 pan to measure aggregate application rates was found to be suitable for calibration purposes and for construction control.

The existing method of visually rating pavement surfaces for seal-coat design purposes appears to be inadequate. A more objective method for rating pavement surfaces for seal-coat design purposes should be developed to include both surface texture and surface hardness. Mean texture depths as measured by the sandpatch test should be used to characterize the surface texture. The equivalency factors presented earlier can be used for this purpose. Additional work must be done to determine relationships that incorporate a measurement of the surface hardness.

A mean texture depth measurement should be used along with a visual rating to evaluate the in-service performance of seal coats. Deficiencies of obtaining only a visual rating were evident, and the MTD measurement may also be used to estimate the remaining life of a seal coat using the model developed in this investigation.

It appears that the service life of well-constructed seal coats can be estimated for the aggregate and surfaces used in this investigation using the prediction model developed herein. Wear and embedment rates for other aggregates and surfaces should be measured and relationships developed with laboratory tests and field measurements of surface hardness.

REFERENCES

1. J. A. Epps, B. M. Gallaway, and C. H. Hughes. *Field Manual on Design and Construction of Seal Coats.* Texas Transportation Institute, College Station, Tex., 1981.
2. R. Roque, D. A. Anderson, R. A. Robyak, and M. J. Thompson. *Design, Construction, and Performance of Bituminous Seal Coats.* Final Report No. 9008. Pennsylvania Department of Transportation, Harrisburg, Pa., Dec. 1989.
3. C. P. Marais. *Advances in the Design and Application of Bituminous Materials in Road Construction.* Ph.D. thesis. University of Natal, South Africa, 1979.
4. R. R. Long and P. L. Melville. *A Surface Treatment Management System.* Report FHWA/VA-89/11. Virginia Transportation Research Council, Charlottesville, Dec. 1988.
5. N. W. McLeod. A General Method of Design for Seal Coats and Surface Treatments. *Proc., Association of Asphalt Paving Technologists,* St. Paul, Minn., Vol. 29, 1960.
6. A. Nagi. PennDOT Seal Coat Meeting, Harrisburg, Pa., June 14, 1989.
7. Pennsylvania Department of Transportation. *Bituminous Concrete Mixtures, Design Procedures and Specifications for Special Bituminous Mixtures.* Bulletin 27. Harrisburg, Pa., 1983.
8. M. J. Thompson. *Performance of Bituminous Seal Coats: Measurement and Prediction.* M.S. thesis. Pennsylvania State University, University Park, Aug. 1990.
9. B. E. Sabey. *Road Surface Texture and Change in Skidding Resistance with Speed.* Report No. 20. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1966, 19 pp.
10. N. W. McLeod. Basic Principles for the Design and Construction of Seal Coats and Surface Treatments with Cutback Asphalts and Asphalt Cements. *Proc., Association of Asphalt Paving Technologists,* St. Paul, Minn., Vol. 38, 1969.

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