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16. Abstract


The primary purpose of this report is to summarize the analysis and evaluation of the use of PG-graded asphalt for seal coats. The adoption of the PG grades will obviate the need to continue the viscosity and/or penetration grades and will begin a specification system based on performance. Recommendations include the following:

1. The recommended selection criteria for the asphalt binder using the new PG Superpave grading system are based on high and low pavement design temperatures and on traffic levels. Information contained in this report should be used to determine the proper PG grade of asphalt to be utilized in the various areas of the state. It is recognized that additional field experience may require adjusting these recommendations.

2. Field personnel should evaluate the recommended PG grades in their region of the state to determine whether the grades are satisfactory.

3. Asphalt cements which must be heated to a temperature in excess of 190° C in order to spray should, instead, be emulsified.

4. Recommendations contained in Appendix B should be followed to maximize the probable success of the seal coat.

5. The contractor must submit a seal coat design for approval prior to beginning construction of the seal coat.

These conditions should be addressed in follow-up evaluations of the use of the PG grading system.


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# THE USE OF THE SUPERPAVE PG GRADING SYSTEM FOR SELECTING ASPHALT BINDERS FOR SEAL COATS


by

William E. Elmore
Thomas W. Kennedy
Mansour Solaimanian
Robert McGennis


**Research Report 1367-2F**


Research Project 0-1367

*Performance-Based Seal Coat Asphalt Specifications*

conducted for the

**TEXAS DEPARTMENT OF TRANSPORTATION**

in cooperation with the

**U.S. Department of Transportation**
**Federal Highway Administration**

by the

**CENTER FOR TRANSPORTATION RESEARCH**
Bureau of Engineering Research
**THE UNIVERSITY OF TEXAS AT AUSTIN**

February 1997

## IMPLEMENTATION RECOMMENDATIONS

Performance-based specifications were developed by the Strategic Highway Research Program (SHRP) asphalt research program for hot mixed asphalt concrete. The asphalt binder specification was an integral part of those specifications and includes the newly developed and the soon to be adopted tests for measuring those properties determined critical. The binders for use in seal coats were not included in the SHRP study. The results of the present study determined that the binders currently being used in seal coats will meet the limitations established for asphalt binders by SHRP's Superpave grading system. This final phase of the project establishes the procedures for the selection of the most desirable asphalt binder to meet the particular environmental and traffic conditions. It is expected that there will be significant savings and benefits to TxDOT through the implementation of the Superpave PG Grading System for asphalt binder specifications for seal coats as a result of:

1. using a system that is expected to improve seal coat performance;
2. utilizing the same test equipment and asphalt grading system for asphalt binders in asphalt concrete and seal coats; and
3. simplifying specification criteria, since the properties of the final product are important without the need to specify the type and quantities of the modifiers or establish criteria on the properties of the original materials.

Prepared in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration

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The success of this project was possible only through the cooperation and assistance of district personnel throughout the state and through the guidance of Darren Hazlett of the Materials and Tests Division, who also represented the Department as the Project Director.

The authors also gratefully acknowledge the input and effort of Eugene Betts, the close support of the Center for Transportation Research, and the input of the special advisory panel: Darren Hazlett, TxDOT; Roger Welsh, AGC; Gary Fitts, Asphalt Institute; James Moulthrop, consultant; and Ronald Cominsky, consultant.

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Thomas W. Kennedy, P.E. (Texas No. 29596)
*Research Supervisor*

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## SUMMARY

The primary purpose of this report is to summarize the analysis and evaluation of the use of PG-graded asphalt for seal coats. The adoption of the PG grades will obviate the need to continue the viscosity and/or penetration grades and will begin a specification system based on performance. Our recommendations include the following:

1. The recommended selection criteria for the asphalt binder using the new PG Superpave grading system are based on high and low pavement design temperatures and on traffic levels. Information contained in this report should be used to determine the proper PG grade of asphalt to be utilized in the various areas of the state. It is recognized that additional field experience may require adjusting these recommendations.
2. Field personnel should evaluate the recommended PG grades in their region of the state to determine whether the grades are satisfactory.
3. Asphalt cements which must be heated to a temperature in excess of 190° C in order to spray should, instead, be emulsified.
4. Recommendations contained in Appendix B should be followed to maximize the probable success of the seal coat.
5. The contractor must submit a seal coat design for approval prior to beginning construction of the seal coat.
6. It is noted that:

    a. The cold temperatures are surface temperatures assuming that the surface temperatures are equal to the ambient air temperature. The high temperatures are those 20 mm below the surface and are estimated using the Superpave algorithm. Thus, these defined temperatures were used to establish the temperature regimen shown in the above map figures. Ultimately, it may be desirable to redefine the temperatures for the purpose of specifying asphalt binders for seal coats.

    b. None of the Superpave binder test procedures address the very real problem of short-term aggregate loss due to incompatibility between the asphalt binder and aggregate. It is possible that another SHRP product (e.g., the net adsorption, desorption test) could be used to address this issue, but no testing was accomplished under this project to test this hypothesis.

These conditions should be addressed in follow-up evaluations of the use of the PG grading system.

# CHAPTER 1. INTRODUCTION

## 1.1 BACKGROUND AND SIGNIFICANCE OF WORK

This is the final report for Research Project 1367, "Performance-Based Seal Coat Asphalt Specification," which was undertaken to develop performance-based seal coat asphalt specifications. Previously, modified and unmodified asphalts for seal coats have been specified in terms of viscosity at 60° C or penetration at 25° C, based primarily on the experience of the state, local district, or individual engineer (1). Because these properties are intermediate to high temperature characteristics, they are not good indicators of performance in asphalt mixtures and seal coats. Moreover, in asphalt emulsion specifications, the allowable range for the viscosity and penetration values of the asphalt residue is very large.

***Superpave Asphalt Binder Specifications***

In 1987 the Strategic Highway Research Program (SHRP) began developing a new system for specifying and designing asphalt materials. The final product of the SHRP asphalt research program is a new system called Superpave, short for *Su*perior *Per*forming Asphalt *Pave*ments (2). The system includes an asphalt binder specification and a mixtures design and analysis system, including performance-based tests. Software that supports the overall system and provides performance predictions is also an integral part of the total system. The unique feature of the Superpave system is that it is a performance-based specification and design system. The Superpave asphalt binder tests measure physical properties that relate directly to field performance of hot mixed asphalt concrete for the temperature and loading conditions encountered in the field.

A unique feature of the Superpave binder specification is that instead of performing a test at a constant temperature and variously measuring the viscosity or penetration values, the specified value of stiffness is constant, and the test temperature at which the value must be achieved is determined. Performance graded (PG) binders are defined by a term such as PG64-22. The first number, 64, is the high temperature grade. This means that the binder possesses adequate stiffness properties to withstand a pavement temperature of at least 64° C. Thus, the first number corresponds to the high pavement temperature in the climate in which the binder is expected to be used. Likewise, the second number, -22, is the low temperature grade and means that the binder possesses adequate stiffness properties to minimize thermal cracking of the pavements at a temperature of -22° C or higher.

The new binder specification will replace the viscosity and penetration grades with a system that will eliminate the need for specification proliferation caused by agencies making changes to presumably improve performance of asphalt mixtures. The federal transportation department and most state transportation departments, including TxDOT, are currently moving to adopt these specifications in 1997. A recent report released by the Federal Highway Administration states that a majority of the states have or will be building Superpave pavements this year (3). Spray applications of modified and unmodified binders, e.g., seal coats, purposely were not included in the development of the initial SHRP specifications. Thus, unless the penetration and viscosity grading systems are retained, it is necessary to relate the Superpave binder grades to seal coats and spray applications and to specify emulsions and cutbacks in terms of the Superpave binder specification.

## 1.2 OBJECTIVES OF THE STUDY

The objectives of the study were to:

1. Produce a generic, performance-based specification for seal coat binders using the Superpave binder specification and tests;
2. Produce a specification that is applicable to asphalt cement, emulsion residue, and cutback residue, whether modified or unmodified;
3. Document laboratory performance of seal coat asphalts typically used in Texas, and provide a database of properties for comparison to field performance of binders utilized in places with different traffic and climatic conditions; and
4. Produce guidelines and specifications for seal coat binders that allow TxDOT to purchase cost-effective pavement treatments.

This phase of the study was to develop a draft seal coat[1] binder specification using modified or unmodified asphalt cements graded to satisfy the Superpave asphalt binder specification. Subsequently, this seal coat specification can be evaluated for use by the Texas Department of Transportation.

Objective Number 3 was addressed and reported in Report 1367-1 (4). This report concerns the development of recommended procedures for protocols and criteria for selecting a binder in terms of the anticipated conditions (i.e., climate and traffic) using the Superpave specifications. In addition, recommendations related to design and construction are included.

## 1.3 IMPLEMENTATION AND BENEFITS

It is expected that there will be significant savings and benefits to TxDOT through implementing performance-based specifications for seal coat binders, particularly as a result of:

1. Using a system that is expected to improve seal coat performance and delay the need for maintenance;
2. Utilizing the same test equipment and asphalt grading system for asphalt binders used in asphalt concrete and seal coat; and
3. Simplifying specification criteria, since the properties of the final product are important without the need to specify the type and quantities of the modifiers or establish criteria on the properties of the original materials.

---

[1] Various organizations have developed strict definitions for terms like "seal coat," "surface treatment," "chip seal," etc. In this report, the term *seal coat* is used in a generic sense to indicate all spray application of asphalt followed by an application of cover aggregate.

## 1.4 RESEARCH APPROACH

To satisfy the objectives of this phase of the research, the following approach was followed as closely as possible:

1. Apply the factors known to influence performance of the surface treatments.
2. Apply the material properties that are related to the critical distress mechanisms.
3. Apply Superpave test methods and procedures to provide the required properties for seal coats.
4. Develop a trial draft specification based on the Superpave guidelines and principles.

## 1.5 SCOPE AND ORGANIZATION OF THE STUDY

Chapter 2 of this report outlines the experimental procedures followed to develop the proposed specification. Discussion of the results obtained following the Superpave guidelines are presented in Chapter 3. Finally, recommendations are presented in Chapter 4, along with a recommended draft binder specification. Appendix A includes an abbreviated version of the Superpave binder specification as executed by the American Association of State Highway and Transportation Officials (AASHTO). Given the importance in understanding the properties of the factors being addressed, Chapter 2 of the initial report, Report 1367-1 (4), is repeated here in a modified form as Appendix B. Included in this appendix is a discussion of the factors influencing the performance of seal coats and the distress mechanisms in surface treatments. Also reported are the results of the literature review on performance of seal coats, together with the references showing the contributions of previous researchers. The resulting document in Appendix B is an outline for a potential guideline for obtaining a successful seal coat using the Superpave system.

# CHAPTER 2. EXPERIMENTAL PROGRAM

It is necessary to utilize the Superpave PG grading system, or at least to specify a subset of the PG grading system, to eliminate the need for an additional grading system. The objective of this phase of the program is to utilize the Superpave binder specification for seal coats and base the selection on climate and traffic conditions. The following procedures were followed to develop the draft specification:

1. Identify the factors known to influence performance of the surface treatments.
2. Identify the asphalts utilized for seal coats:
   a. determine whether there were patterns related to geographical/climate factors and traffic; and
   b. determine the reasons for the individual selection of specific grades or types.
3. Determine the PG grading of the asphalts utilized.
4. Relate the asphalt grades and properties to temperature and traffic by means of the Superpave binder specification.
5. Determine regional or individual environmental extremes:
   a. develop and graphically locate existing long-term weather data indicating the potential maximum and minimum temperatures for the state of Texas; and
   b. identify the approximate limits based on the applicable temperature extremes that are compatible with the Superpave specification grading.
6. Develop an asphalt binder specification in matrix form based on anticipated temperatures and traffic and recommend related procedures for aggregates, design, and construction.

## 2.1 IDENTIFY THE FACTORS KNOWN TO INFLUENCE PERFORMANCE OF THE SURFACE COATS

Early in this phase of the study an advisory group consisting of Roger Welsch (AGC), Ronald J. Cominsky (consultant), James Moulthrop (consultant), Gary Fitts (Asphalt Institute), Darren Hazlett (TxDOT), and the researchers developed an eight-question questionnaire specifically directed to seal coat operations. This questionnaire was submitted to a broad cross section of experienced and nationally recognized experts in the field of asphalt and its application. The questionnaire and the 21 responses we received are summarized and discussed in Chapter 3.

## 2.2 IDENTIFY THE ASPHALTS UTILIZED FOR SEAL COATS

The TxDOT standard (8) and special specifications presently provide for the use of asphalt binders in various forms to be used for seal coats without imposing any limitations pertaining to location. Prior to establishing a relationship for the Superpave grading system, it was critical to determine which current grades and types of binders were presently being used and where and why these grades were being used.

## 2.3 DETERMINE THE SUPERPAVE GRADES FOR ASPHALTS UTILIZED

Asphalt binders currently being used in Texas for seal coats were tested using the Superpave binder tests to determine the Superpave PG grades. This required sampling the currently used binders and performing the prescribed laboratory tests (6). The methods used were developed and reported in Report 1367-1 (4). In order to test emulsion asphalts, the residue had to be obtained by either the standard evaporation or the distillation process. The testing matrix shown here in Table 2.1 was designed to determine the desirable procedure.

*Table 2.1 Testing matrix to evaluate effect of emulsion residue recovery method*

| Binder | Recovery Method | Test Temperature, °C | | | | | |
|---|---|---|---|---|---|---|---|
| | | 52 | | 58 | | 64 | |
| | | G* | δ | G* | δ | G* | δ |
| CRS-2 | evaporation | √ | √ | √ | √ | √ | √ |
| | distillation | √ | √ | √ | √ | √ | √ |
| | base | √ | √ | √ | √ | √ | √ |
| HFRS-2 | evaporation | √ | √ | √ | √ | √ | √ |
| | distillation | √ | √ | √ | √ | √ | √ |
| | base | √ | √ | √ | √ | √ | √ |
| HFRS-2P | evaporation | √ | √ | √ | √ | √ | √ |
| | distillation | √ | √ | √ | √ | √ | √ |
| | base | √ | √ | √ | √ | √ | √ |
| √ - indicates one determination per cell | | | | | | | |

## 2.4 RELATE THE ASPHALT PROPERTIES TO SUPERPAVE BINDER SPECIFICATION

The asphalts presently used by TxDOT were identified in terms of the Superpave binder grades and were reported in detail in the first report, 1367-1.

## 2.5 DETERMINE STATEWIDE TEMPERATURE EXTREMES

The SHRP Asphalt Research Program developed a weather database for the North American continent. That information as it pertained to the state of Texas was used to develop the maps shown in Chapter 3 by taking the averages and extremes reported for the weather stations through the states and using the information to plot isotherms.

In order to determine the most desirable locations for utilizing the available asphalt binders within the state, this existing history of the maximum and minimum temperature extremes was then used to delineate the regional or individual areas best suited for the Superpave binder specification classifications.

## 2.6 DEVELOP THE SEAL COAT SPECIFICATION BASED UPON THE SUPERPAVE SYSTEM

A specification was now possible to be developed that incorporates the Superpave nomenclature, tests, and recommended location for use of each of the available asphalt binders.

## 2.7 IDENTIFY LIMITS OF USE BY SPECIFICATION GRADES AND EXPECTED TEMPERATURES

The Superpave specification grades also indicate the temperature limits at which they can be expected to perform best. These limits were charted on the maps in Chapter 3 by using the information plotted in section 3.3 and marking the general demarcation between the specification grade limits.

## 2.8 DEVELOP THE SPECIFICATION MATRIX

Utilizing the plotted weather temperature extremes that were applicable to Texas, it was then possible to develop the specification matrix recommended for trial use by TxDOT.

Although the selected groupings in the proposed matrix were defined by applying experimental data, these have been favorably proven to date in those field trials using the Superpave specifications for hot-mix asphalt concrete pavements.

# CHAPTER 3. ANALYSIS OF RESULTS

The focus of this project was to develop a specification or selection procedure for seal coat binders based on and using the Superpave binder specification and tests. To achieve this goal, the project was performed in two phases. The first phase of the development involved the determination of the asphalt binders and their physical characteristics, as measured by the tests adopted by the Superpave system. The final phase was to determine the environmental parameters in the state and then adapt the Superpave grades. The result is a draft of a Superpave binder specification selection procedure for seal coat binders.

## 3.1 IDENTIFY THE FACTORS KNOWN TO INFLUENCE PERFORMANCE OF THE SEAL COATS

The advisory group compiled a listing of 37 potential responders to the questionnaire developed to obtain input on the placement of seal coats. Twenty-seven were contacted and twenty-one responses were received. The responders included eight highway users, seven consultants, five suppliers, and one seal coat contractor. Responses to the questions in order of priority, based upon responses to each question, were:

1. PLEASE NAME THE MOST CRITICAL FACTORS IN ACHIEVING SUPERIOR SEAL COAT PERFORMANCE.
   - The amount of asphalt used. Always require a design.
   - Condition of the aggregate (clean or dry).
   - Environmental conditions.
   - Workmanship.
2. USE OF MODIFIED ASPHALTS:

   WHY DON'T YOU USE SPECIFIC ASPHALTS AND WHICH ARE THEY (i.e., AC 20, 30, SPECIFIC POLYMERS, etc.)?
   - Modified AC-5 or AC-10 coats and holds aggregate better than emulsions.
   - Experience has shown that certain combinations of materials are needed for successful seal coat.
   - The extra cost for polymers is not justified.

   WHAT CONDITIONS OF CONSTRUCTION WOULD REQUIRE A MODIFIED ASPHALT?
   - High traffic volume and early release to traffic.
   - Temperature at time of construction.

   WHAT EXISTING ROAD CONDITIONS WOULD REQUIRE A MODIFIED ASPHALT?

- High Average Daily Traffic.
- Existing surface cracks in old surface.

WHAT TRAFFIC LEVEL WOULD REQUIRE USE OF A MODIFIED ASPHALT?

- 2500 ADT and above.
- High speed or extreme turning areas and high truck traffic.

3. WHAT CONDITIONS WOULD CAUSE THE USE OF AN EMULSION OVER AN AC GRADE OR THE SELECTION OF THE AC GRADE OVER EMULSION?
    - Some preferred the use of emulsions in all cases, but many used emulsions in cool weather and required an AC grade in extremely hot conditions (+100° F).

4. WHAT FACTORS WOULD CAUSE YOU TO SELECT A CRS-2 INSTEAD OF AN HFRS-2 (OR REVERSE)?
    - CRS-2 adheres to aggregate better and is preferred when rain threatens.
    - HFRS-2 needed to permit early traffic operations.

5. WHAT HAS BEEN YOUR EXPERIENCE IN COMPARING THE ACTUAL LIFE OF A SEAL COAT VS DESIGN LIFE?
    - Most seal coats last to the design life when designed and constructed properly.

6. IN YOUR EXPERIENCE, WHAT HAS BEEN THE CAUSE OF MOST SHORT-TERM FAILURES IN SEAL COATS?
    - Rain or low temperatures.
    - No design or improper design.
    - Condition of existing road surface.
    - Improper equipment calibration or contractor qualifications.

7. HOW DO YOU PROVIDE FOR THE LEVELS OF ANTICIPATED TRAFFIC (ESALS)? WHAT VARIATION IN YOUR DESIGNS?
    - Include provisions for modifications in the design provisions for application and construction procedures.

8. ANY RECOMMENDATIONS FOR CHANGES IN ASPHALT SPECIFICATIONS, SELECTION PROCESS, DESIGN, OR CONSTRUCTION PROCEDURES? ANY GENERAL REMARKS?
    - Proper laboratory design of the seal coat to include asphalt and aggregate compatible to each other.
    - Enforcement of the specifications and proper construction practices.

## 3.2 IDENTIFY THE ASPHALTS UTILIZED FOR SEAL COATS

All TxDOT districts were contacted to determine which asphalts they were using for seal coats, any limiting factors, and the basis for the selection of particular binder types or grades. This information was accumulated and reported in Report 1367-1 (4). Based on this information, seal coat asphalt binders were selected for testing. The asphalts sampled and evaluated are listed in Table 3.1, along with asphalts not being used and, consequently, judged to be unsuitable. These unsuitable asphalts were tested to provide a clear reference when adapting to the Superpave grading system.

*Table 3.1 Seal coat binders sampled and evaluated*

| Suitable Binders | Unsuitable Binders |
|---|---|
| AC-5 | |
| AC-5 (2 % latex) | |
| AC-10 (2 % latex) | |
| AC-15P | AC-1.5 |
| AC-15-5TR | AC-3 |
| AC-20 | AC-30 |
| CRS-2 | |
| CRS-2P | |
| HFRS-2 | |
| HFRS-2P | |

The asphalt binder sources determined to be currently available for use are shown in the Table 3.2.

*Table 3.2 Grades and sources of binders used in study*

| Grade | Source |
|---|---|
| Unsuitable Binders | |
| AC-1.5 | Kerr-McGee, Gulf States Asphalt |
| AC-3 | Total Petroleum, Exxon Co., Lion Oil, Kerr-McGee, Fina |
| Suitable Binders | |
| AC-5 | Diamond Shamrock, Fina, Chevron, Exxon, Texas Fuel & Asphalt, Neste/Wright, Coastal Refining, Total, Kerr-McGee |
| AC-5 (2% latex) | Fina, Coastal Refining, Texas Fuel & Asphalt, Trumbull |
| AC-10 (2% latex) | Coastal, Texas Fuel & Asphalt |
| AC-15P | Texas Fuel & Asphalt, Neste/Wright, Koch Materials |
| AC-15-5TR | Neste/Wright |
| HFRS-2 | Koch Materials[1] |
| HFRS-2P | Koch Materials[1] |
| CRS-2 | Koch Materials[1] |
| CRS-2P | Koch Materials[1] |
| [1] Source of base asphalt not identified. | |

Official samples were obtained from samples sent to TxDOT's Materials and Tests Division for routine testing.

In addition to the request for the asphalt binders being successfully used for seal coats, the TxDOT districts were asked: "How was the asphalt binder selected?" It was anticipated that there might be a pattern based on temperature or geographic extremes. Analysis of the replies clearly indicated that there was no clear-cut pattern. All types were found to be used in every region of the state.

## 3.3 DETERMINE THE PG GRADING OF THE ASPHALTS UTILIZED AND RELATE TO SUPERPAVE TEMPERATURE AND TRAFFIC LIMITS

All of the asphalt cements and emulsion asphalt residues were tested using the tests developed for use with the Superpave binder specification system. The two processes used for obtaining their residue were the standard evaporation and distillation procedures. A testing matrix, as shown in Table 2.1, was designed using a representative sample of each emulsion and tested by both methods to determine the desirable procedure.

This procedure is discussed in detail in Report 1367-1. Based upon the results of these tests, the distillation method, Texas Test Method Tex-521-C (6), which is identical to ASTM D-244 (5), was selected.

The Superpave binder grades are classified by the maximum pavement temperature at which they are expected to perform satisfactorily and the low temperatures they are expected to encounter. Therefore, in order to properly determine the classification of the presently used asphalt binders in terms of the Superpave grades (PG grades), it was necessary to analyze these binders by using the tests developed by the SHRP asphalt research program and by applying the established limits as set forth in the Superpave Binder Specification (Appendix A). This was reported in Report 1367-1 (4), along with a complete description of the tests and their nomenclature and an explanation of the PG grading system. A portion of those results is summarized herein to provide the background for developing the seal coat specification.

***High Pavement Temperature Analyses***

Properties of seal coat binders at high temperatures directly contribute to the resistance to bleeding and short-term aggregate loss. A very stiff binder at high pavement temperatures would not tend to bleed because it would be too stiff to flow. A very stiff binder at high pavement temperatures would more rigidly maintain aggregate orientation under traffic, which would also help eliminate bleeding distress because the aggregate could not densify below 20 percent air voids. Likewise, a very stiff asphalt would more tenaciously retain aggregate under the mechanical abrasion of traffic, which would minimize short-term aggregate loss. In terms of the Superpave binder specification, all three high temperature distress mechanisms would be ameliorated by maximizing the stiffness parameter $G^*/\sin\delta$ for both unaged and RTFO-aged binder. The Dynamic Shear Rheometer (DSR) test on the binders give values for the complex shear value ($G^*$) and phase angle ($\delta$) at high temperatures. $G^*$ is a measure of binder stiffness in shear and $\delta$ is an indicator of the degree of elasticity of the binder, both reported for a given test temperature.

A discriminating value of $G^*/\sin\delta$ was sought in the analysis. To find this value, DSR tests were performed at 52°C, 58°C, and 64°C for unaged asphalt and RTFO aged asphalt. A graphical representation is shown in the following figures. Clearly, the RTFO is not intended to simulate aging in seal coat binders; however, the RTFO stiffness data are used in the Superpave PG grading system and, thus, are analyzed to properly frame the binders in terms of the PG system. All binders in the upper-right-hand quadrant satisfy the $G^*/\sin\delta$ stiffness requirements for the designated high temperature.

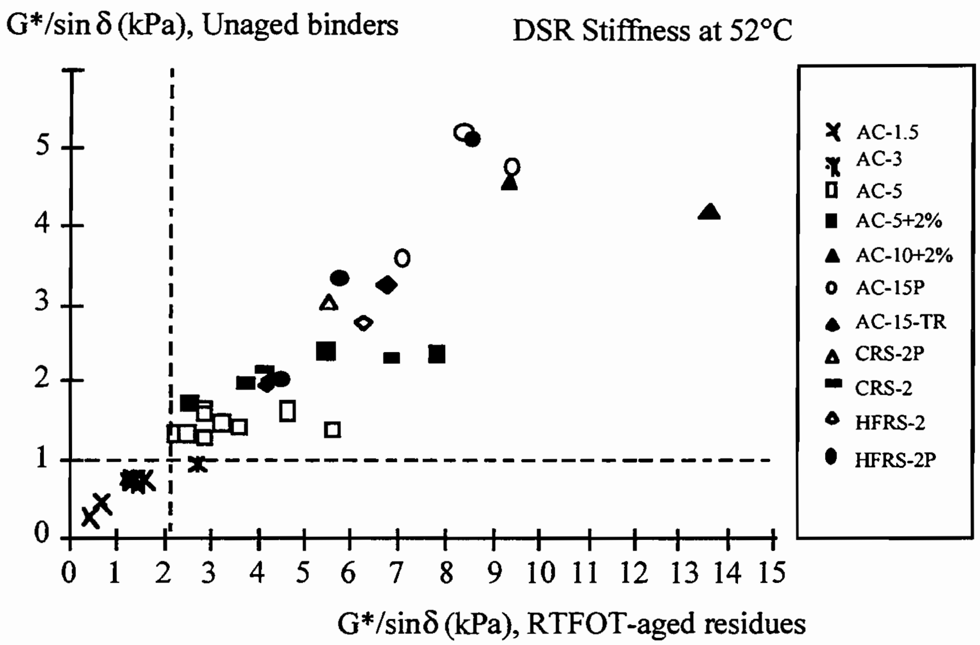


*Figure 3.1 DSR stiffness (G*/sinδ) of unaged and RTFOT-aged binders at 52°C*

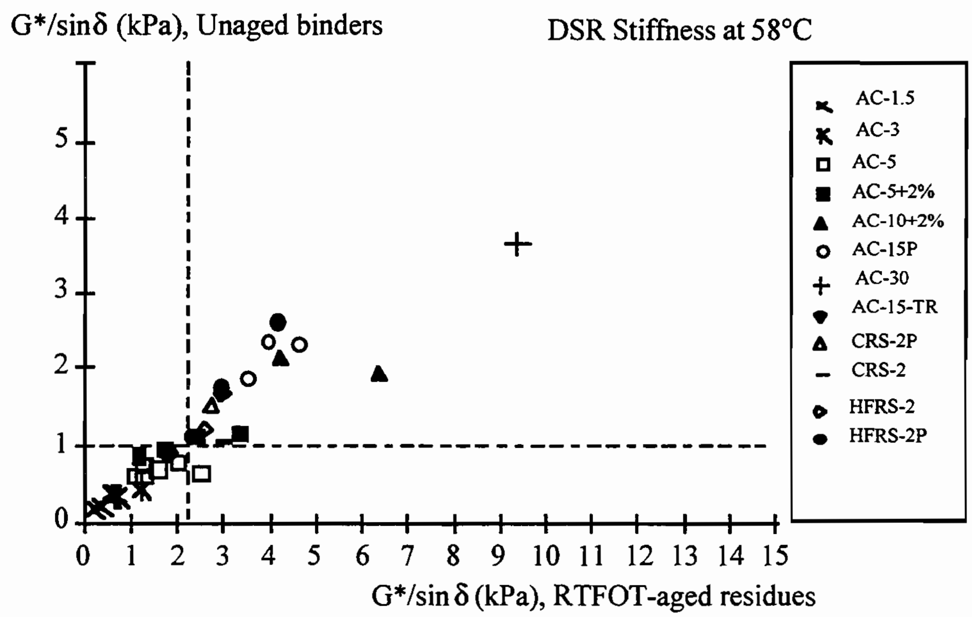


*Figure 3.2 DSR stiffness (G*/sinδ) of unaged and RTFOT-aged binders at 58°C*

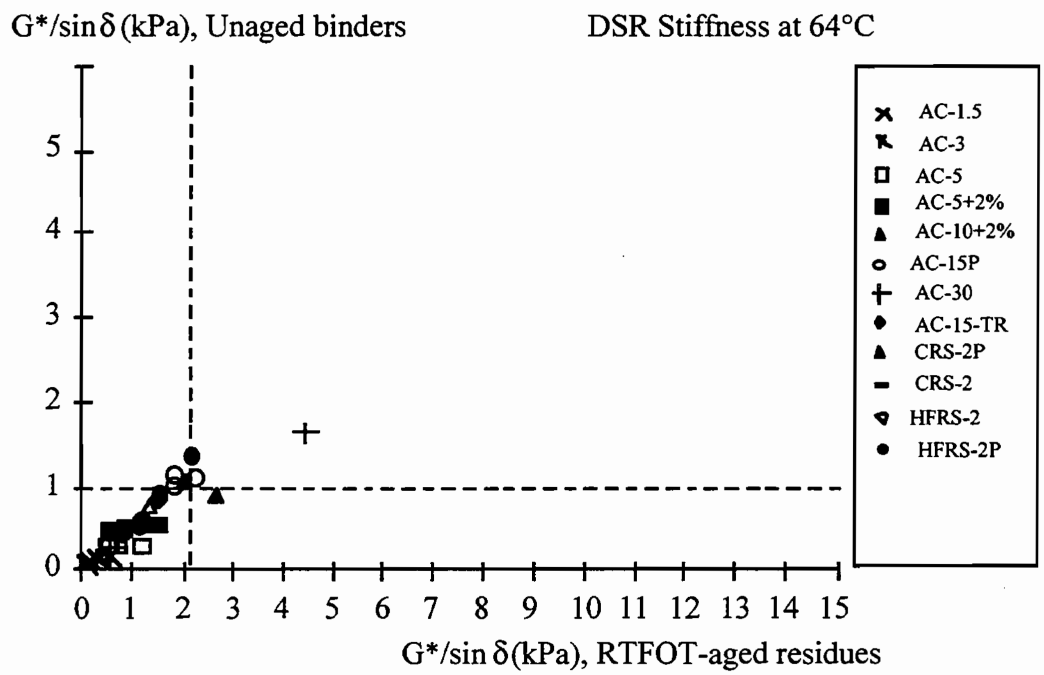


*Figure 3.3 DSR stiffness (G*/sinδ) of unaged and RTFOT-aged binders at 64°C*

It is apparent that for all test temperatures, the grades AC 1.5 and 3 were outside the specification limits. These grades were not reported to be in use in the state for seal coats and thus were judged to be unsuitable. For high temperature properties, a PG 52 with the normal Superpave criterion for unaged asphalt binder and a G*/sin δ of 2.20 kPa for short-term aged asphalt would encompass essentially all currently used seal coat binders. The PG grades of 58-YY and 64-YY do not discriminate between the unsuitable and suitable binders.

It should be noted that none of the Superpave binder test procedures address the very real problem of short-term aggregate loss resulting from incompatibility between the asphalt binder and aggregate. It is possible that another SHRP product (e.g., the net adsorption, desorption test) could be used to address this issue, but no testing was accomplished under this project to test this hypothesis.

### *Low Pavement Temperature Analyses*

Properties of asphalt binders at low temperatures directly contribute to the resistance of seal coats to both short- and long-term aggregate loss. A pliant binder at low temperatures is not as susceptible to aggregate loss. In terms of the Superpave binder specification, this distress mechanism would be ameliorated by minimizing S and maximizing m-value, both measured on PAV-aged materials. Consequently, discriminating values of S and m were sought in the analysis.

The Bending Beam Rheometer (BBR) test provides values for the creep stiffness (S) and the logarithmic creep rate (m), both of which are used to minimize low temperature cracking.

A graphical representation is shown in the following figures for S and m at -12Υ and -18°C. Values in the lower-right quadrant satisfy the Superpave low temperature requirements for the temperature conditions designated.

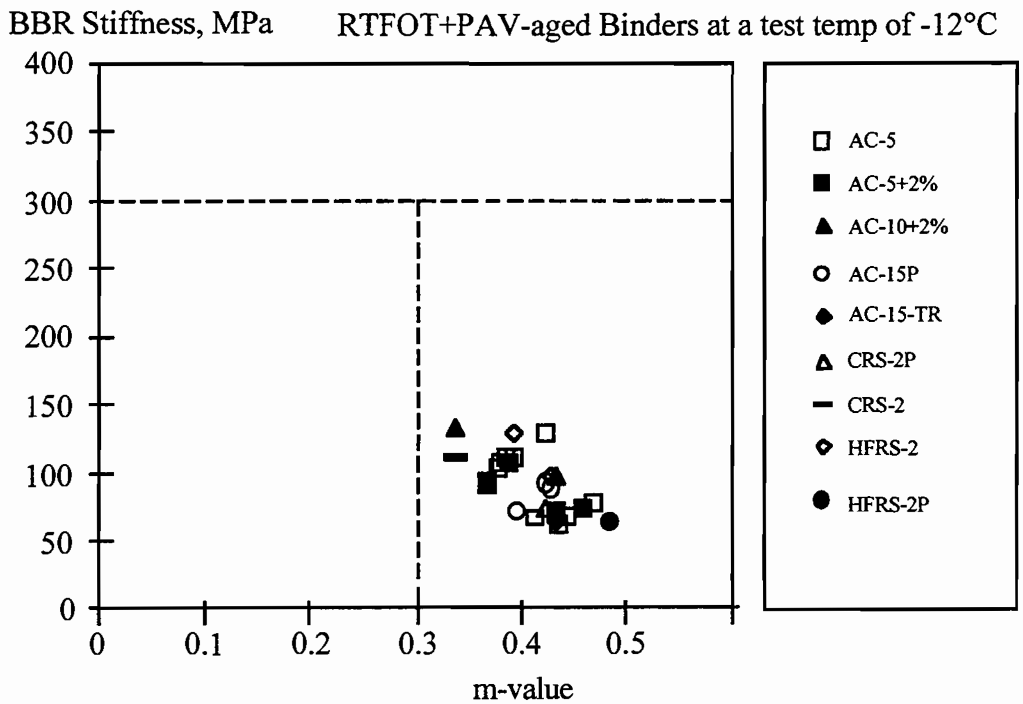


*Figure 3.4 Creep stiffness (S) and logarithmic creep rate (m) of RTFOT+PAV-aged binders at a test temperature of -12 °C*

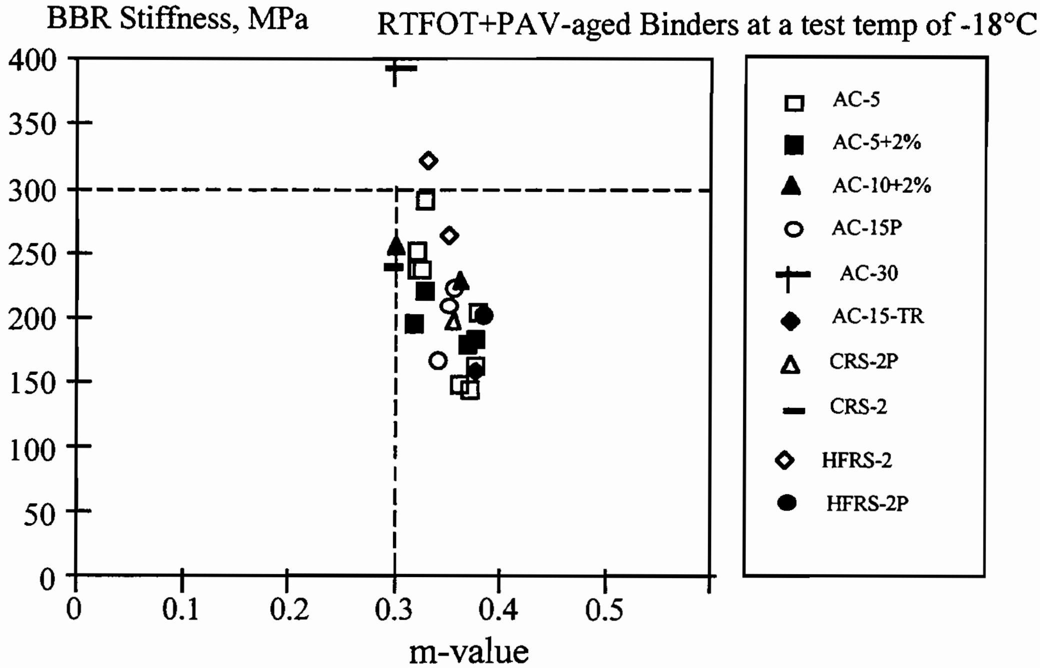


*Figure 3.5 Creep stiffness (S) and logarithmic creep rate (m) of RTFOT+PAV-aged binders at a test temperature of -18°C*

These figures indicate that the binders tested far exceeded the Superpave S and m low temperature criteria at -12°C and classified as PG XX-22 grades. In fact, most of the binders satisfy requirements for a PG XX -28 (test temperature of -18°C). At this temperature, one HFRS-2 binder exceeded the stiffness limitations. A CRS-2 and AC-10 (2%) were marginal on m-value at -18°C.

The following figure shows the stiffness values of unaged asphalt at -18° C. It is possible that these binders simulate the condition of seal coat binders at a very early age, for example, during their first winter when short-term aggregate loss might occur. At this temperature, all binders exhibit stiffness values in the range from about 75 to 175 MPa.

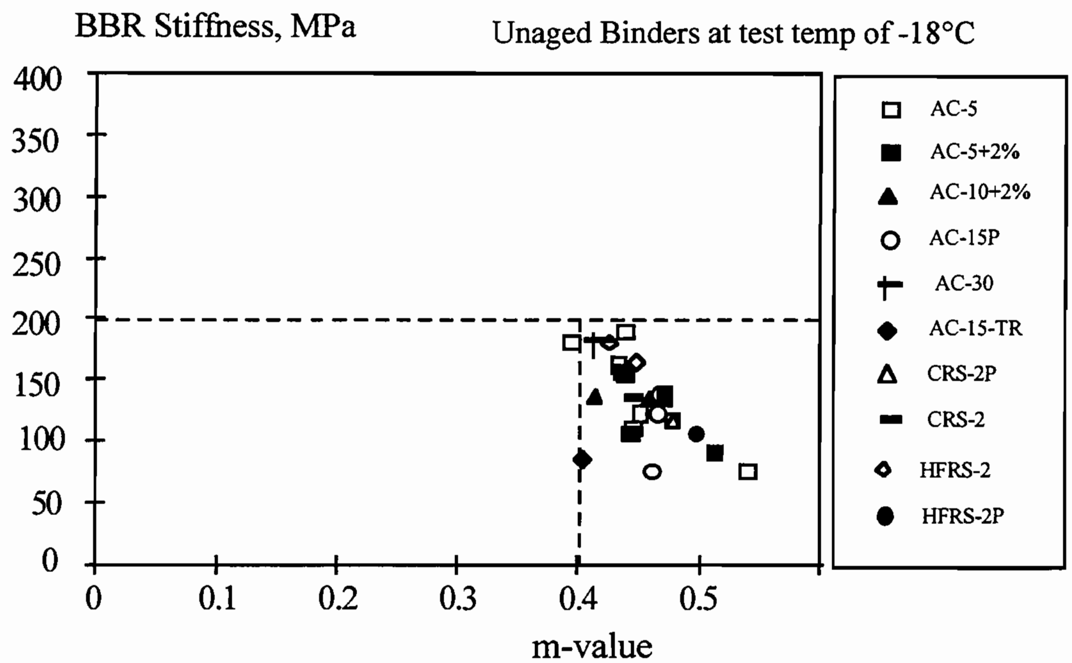


*Figure 3.6 Creep stiffness (S) and logarithmic creep rate (m) of RTFOT+PAV-aged binders at a test temperature of -18°C*

## 3.4 DETERMINE REGIONAL OR INDIVIDUAL ENVIRONMENTAL EXTREMES

### *Develop and Graphically Locate Historical Long-Term Data for Maximum and Minimum Temperatures*

The Strategic Highway Research Program utilized data developed from reporting weather stations to determine the temperature extremes in each area of North America. Data for the state of Texas were extracted and plotted geographically. From these plots the following figures were developed for the variables of high and low traffic loadings and high and low temperature extremes at both 50% and 98% reliability. The reliability indicates the probability that the temperature will not be exceeded. Thus, for high temperatures 50% indicates that there is less than a 50% chance that the temperature will be exceeded in a given year, while 98% indicates that there is less than a 2% chance.

The contours give a general demarcation between areas in which the Superpave grades can generally be expected to perform best.

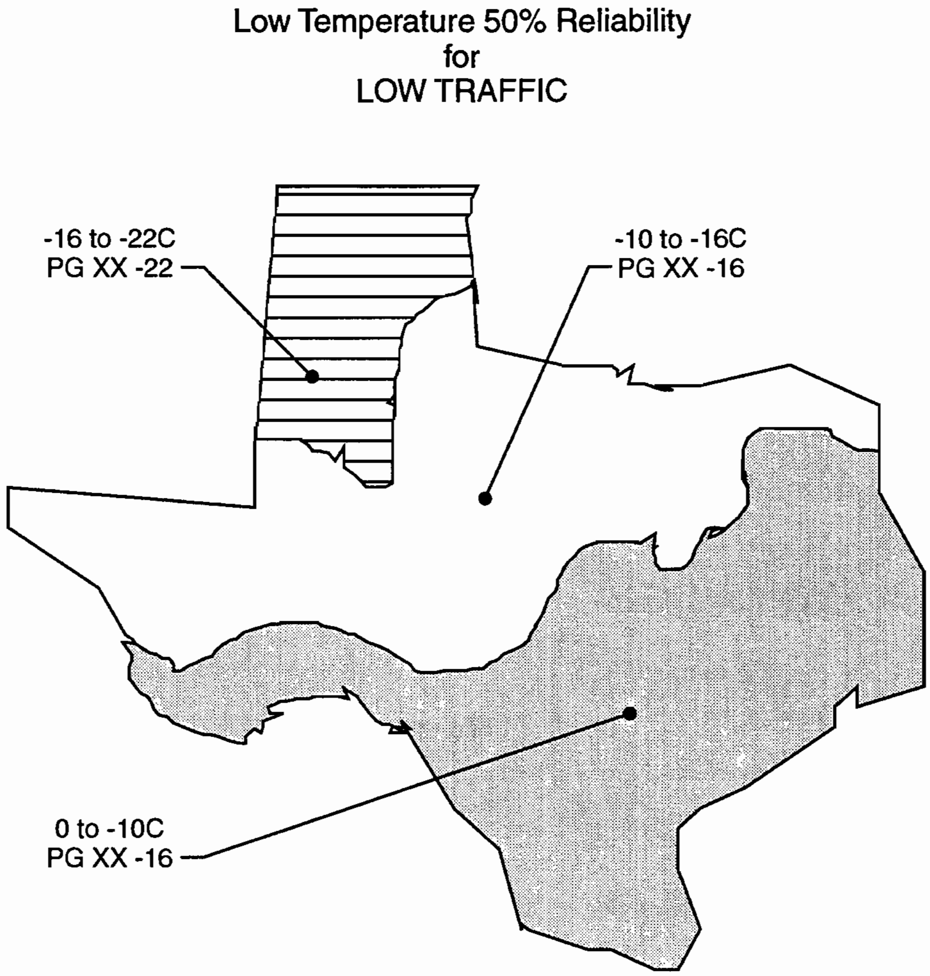


*Figure 3.7 Recommended low temperature asphalt grades for low traffic and 50% reliability*

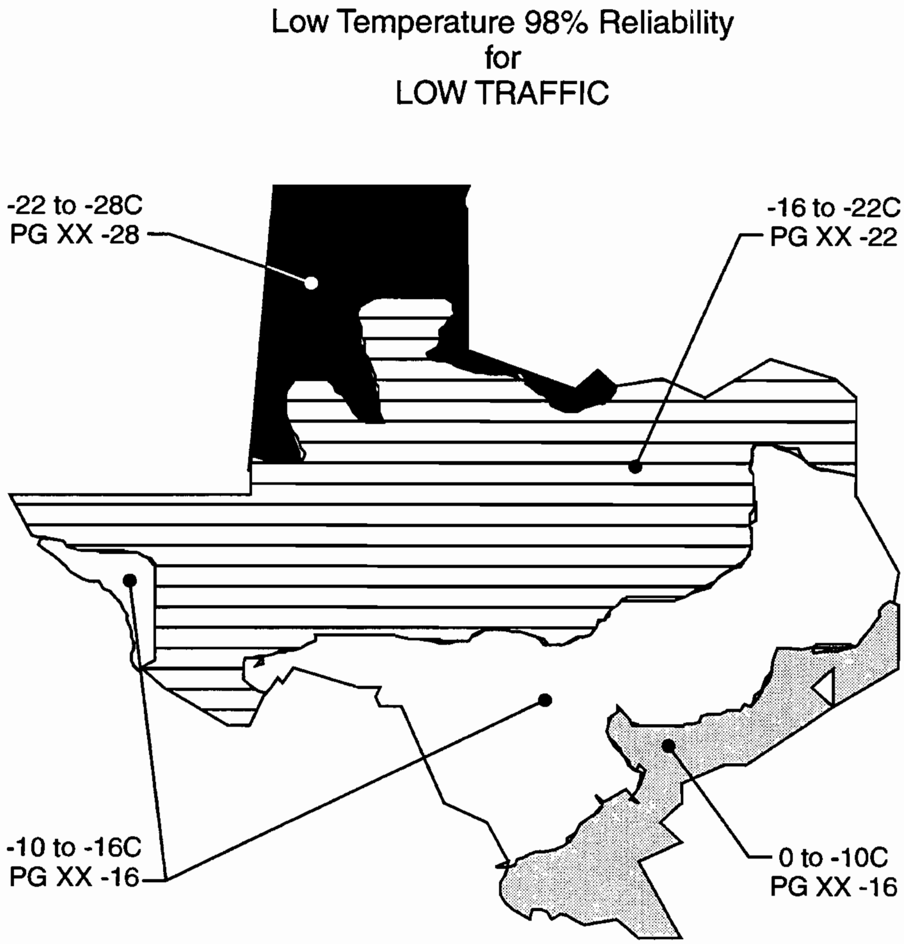


*Figure 3.8 Recommended low temperature asphalt binder grades for low traffic and 98% reliability*

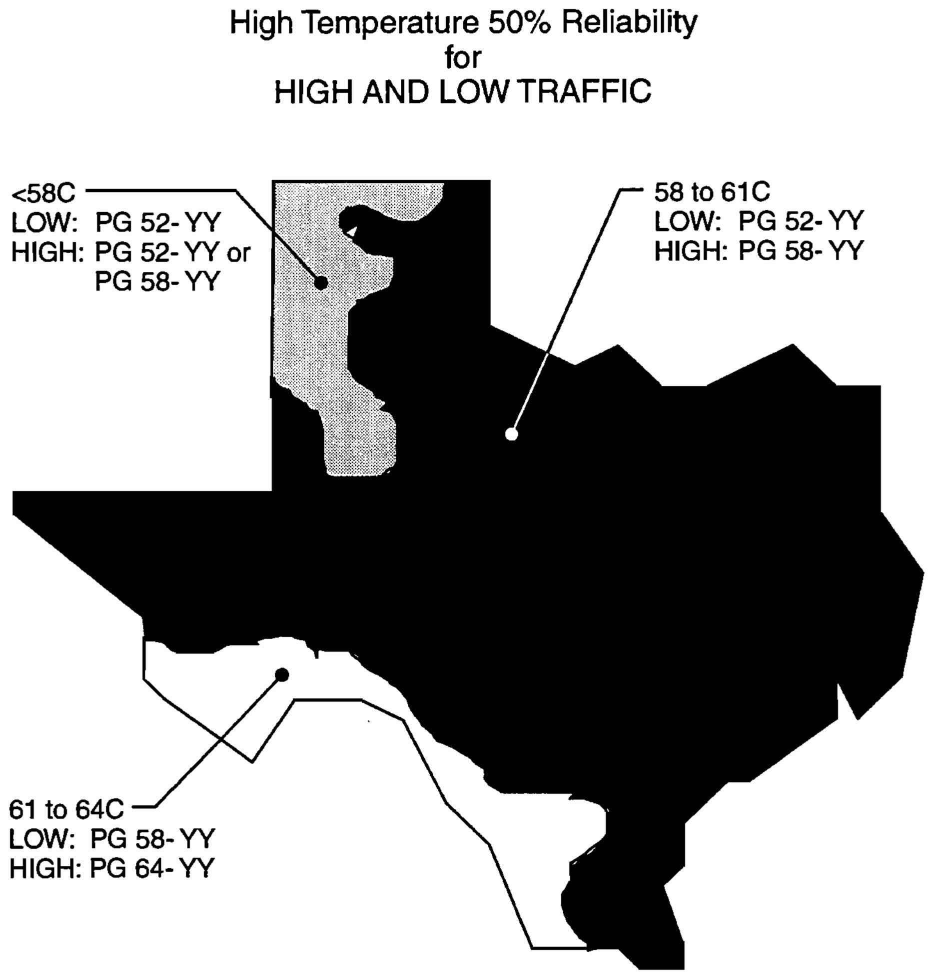


*Figure 3.9 Recommended high temperature asphalt binder grades for high and low traffic and 50% reliability*

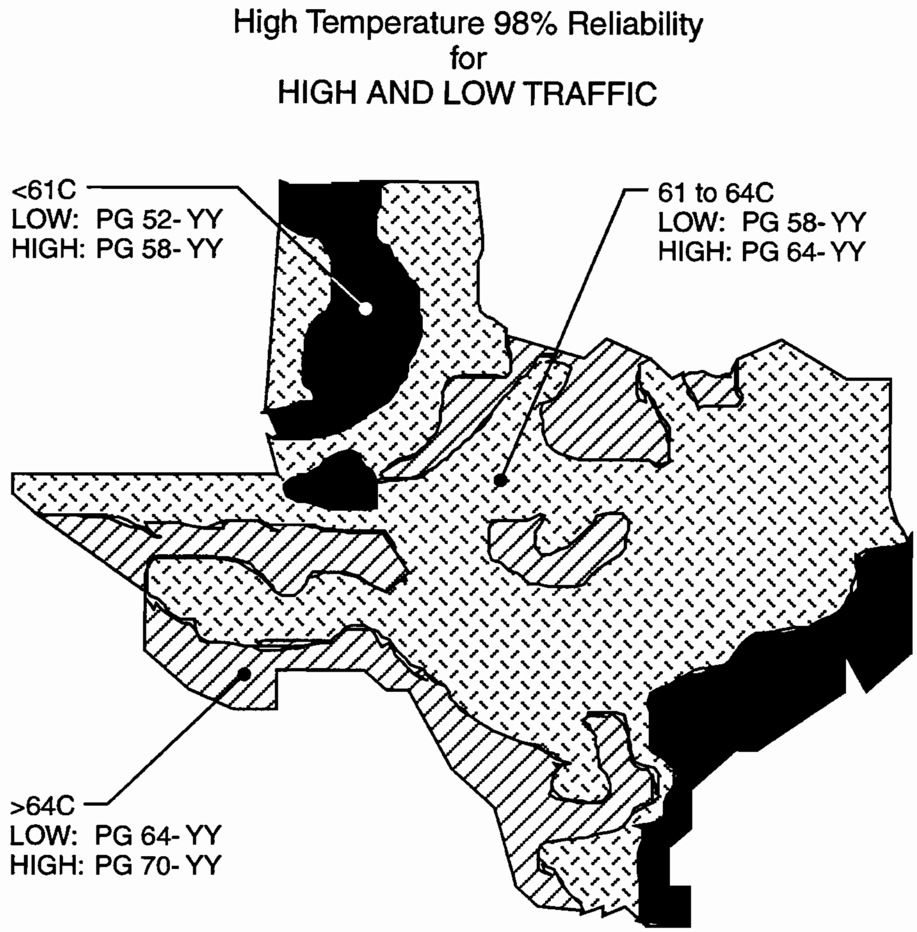


*Figure 3.10 Recommended high temperature asphalt binder grades for high and low traffic and 98% reliability*

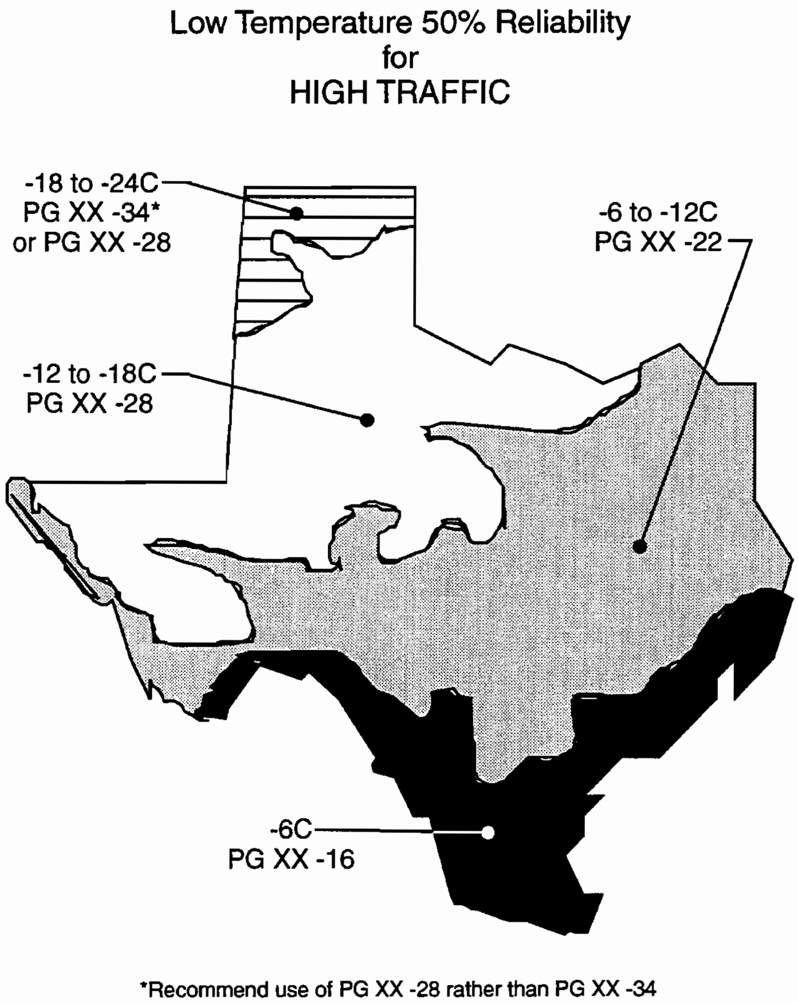


*Figure 3.11 Recommended low temperature asphalt grades for high traffic and 50% reliability*

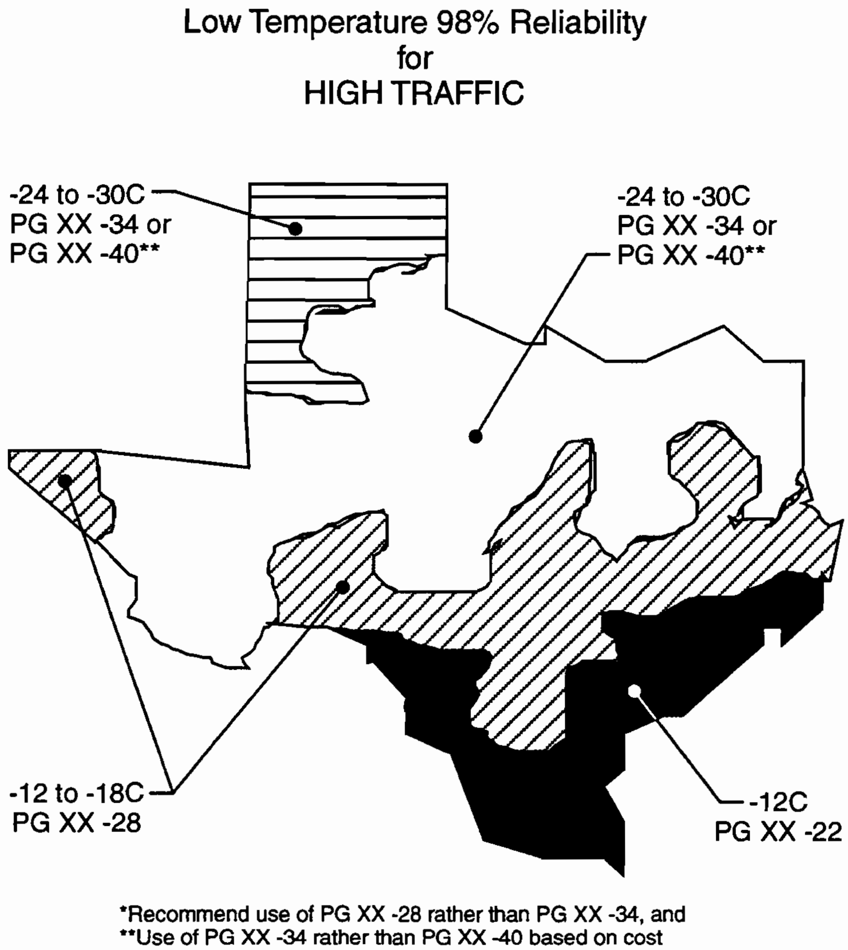


*Figure 3.12 Recommended low temperature asphalt grades for high traffic and 98% reliability*

## 3.5 DEVELOP THE SEAL COAT SPECIFICATION MATRIX

The following chart is based upon the best fit data developed from the tests performed upon the asphalt binder and the traffic and environmental conditions expected to exist at the project site.

The cold temperatures are surface temperatures assuming that the surface temperatures are equal to the ambient air temperature. The high temperatures are those 20 mm below the surface and are estimated using the Superpave algorithm. Thus, these defined temperatures were used to establish the temperature regimen shown in the above map figures. Ultimately, it may be necessary or desirable to redefine the temperatures for the purpose of specifying asphalt binders for seal coats.

*Table 3.3 Asphalt PG grade specifications based on pavement temperatures and traffic*

| | High Pavement Temperature | | | | | |
|---|---|---|---|---|---|---|
| | 61° C | | 64° C | | 70° C | |
| Traffic | High | Low | High | Low | High | Low |
| -16° C | 58–16 | 52–16 | 64–16 | 58–16 | 70–16 | 64–16 |
| -22° C | 58–22 | 52–22 | 64–22 | 58–22 | 70–22 | 64–22 |
| -28° C | 58–28 | 52–28 | 64–28 | 58–28 | | |

# CHAPTER 4. SUMMARY AND RECOMMENDATIONS

## 4.1 SUMMARY

In order to ensure satisfactory performance of seal coats, the following factors must be carefully considered:

- selection of materials,
- design, and
- construction.

While the selection of the binder is of major importance to the long-term performance of a seal coat, the binder has less effect on the short-term performance or behavior. In addition, the characteristics of the asphalt binder may be overwhelmed by the specific design and construction, as described in Appendix B.

## 4.2 SELECTION OF MATERIALS

### *Binder*

The asphalt binder may be either an unmodified or modified asphalt cement, or an emulsion with an unmodified or modified asphalt residue. Regardless of the type selected and designed, the residual asphalt must have the necessary adhesion strength and deformation characteristics to hold the aggregate on the road surface for the desired design or service life. A stiff asphalt would seem to be a desirable material for high-temperature environments. The stiffness, however, is limited by the high temperatures required to effectively spray the asphalt on to the pavement surface, since overheating the asphalt can promote premature aging and render the asphalt brittle, thereby shortening the life of the seal coat. The absolute maximum spraying temperature used by the Texas DOT is 204°C, which is considered to be high and, thus, should be avoided. Instead, a maximum temperature of 190°C should be adopted.

Naturally, it is anticipated that construction will be scheduled such as to avoid inclement weather. There is still a need to base the selection (to a degree) on the time of year, particularly when using emulsions that may break too soon under excessively hot temperatures or be too slow during very cool temperatures.

### *Aggregates*

Important aggregate factors that need to be considered for superior seal coat performance include aggregate size, shape, gradation, durability, porosity, and cleanliness. Aggregate size is a design factor to the extent that it affects the amount of asphalt in terms of a desired embedment depth. Larger aggregates require more asphalt to achieve a prescribed embedment depth.

Aggregate shape is a critical factor insofar as most of the design methods assume aggregate is largely cubical. Some design methods adjust for aggregate shape by means of a parameter termed the *flakiness index.* A flakiness index is used to estimate the average least dimension of the aggregate, which, in turn, is used to compute the required asphalt application rate. A flaky aggregate (i.e., flat and/or elongated) results in a lower asphalt application rate, since its average least dimension is smaller.

Aggregate gradation influences seal coat design and performance in three ways: (1) maximum size, (2) well graded versus uniformly graded, and (3) dust content. Most agencies, including TxDOT, have abandoned the well-graded aggregate in favor of uniformly graded aggregate for seal coats. In general, uniformly graded cover aggregates are advantageous because they tend to be cleaner, do not segregate in stockpiles or during handling, and result in a quieter ride (7), as compared with graded aggregates.

The amount of dust (percent finer than 75 microns) contained by the aggregate affects seal coat performance because the dust prevents bonding between the asphalt and aggregate. It is likely that a certain amount of stone dust material is beneficial in seal coats to achieve the proper void content, though excessive dust on the coarse aggregate is detrimental to adhesion.

Aggregate toughness and durability play a role in seal coat performance because of its effect on aggregate size. If aggregates degrade when manipulated during construction or under traffic or are degraded due to chemical action, they are effectively reduced in size. If this happens, the amount of asphalt applied according to the anticipated size becomes too great (which can then lead to bleeding).

The effect of aggregate porosity on seal coat performance is analogous to that resulting from existing surface conditions. Highly absorptive aggregates require an increase in application rate to satisfy their asphalt demand. Some areas require that a precoated stone be used or that a fog seal be applied soon after the construction of the seal coat.

## 4.3 DESIGN

The products of seal coat design are the application rates for the asphalt binder and the cover aggregate. Asphalt application rate is specified as liters of product per square meter. Aggregate application is designed and specified in two ways: (1) mass spread rate (kilograms of aggregate per square meter of pavement surface), or (2) a volumetric spread ratio (square meters of pavement surface per cubic meter of aggregate). TxDOT normally specifies aggregate application using the volumetric spread ratio method.

Both design methods produce recommended application rates for the asphalt and aggregate and consider the following factors:

1. traffic level,
2. the top size, gradation, bulk specific gravity, and loose unit weight of aggregate,
3. the type of asphalt material (i.e., asphalt cement versus asphalt emulsion),
4. the condition of the existing surface (dry, oxidized versus flushed),
5. desired aggregate embedment depth, and

6. in the case of multiple applications, the number of layers.

The following generalized equations are evident from the various design approaches:

Asphalt Application Rate = $f$(1/T, E, S, A, 1/R)

where

T = traffic factor,

E = aggregate embedment,

S = correction for condition of existing surface,

A = aggregate size, shape, gradation, durability, and porosity, and

R = residual asphalt content of binder (i.e., for asphalt cements R = 1.00).

Aggregate Application Rate = $f$(G, U, W)

where

G = average aggregate size,

U = aggregate loose unit weight, and

W = aggregate wastage factor.

These design factors are discussed in more detail in Appendix B. ***IT MUST BE EMPHASIZED THAT THE CONTRACTOR MUST DEVELOP A DESIGN PRIOR TO BEGINNING CONSTRUCTION OF A SEAL COAT.*** All of the responders to the survey discussed in Chapter 3 clearly supported this requirement.

## 4.4 CONSTRUCTION

Bleeding and aggregate loss are the two most common forms of distress encountered in a newly placed seal coat. Both of these can be minimized with proper seal coat design and by the use of quality materials. But these have little impact if quality construction procedures are not adhered to.

The following factors — cited by TxDOT personnel, by the surveyed panel, and by the technical literature — are some of the construction variables that influence performance of seal coats:

1. longitudinal and transverse variation in the rates of material application,
2. length of time between application of binder and application of aggregate,

3. variation in materials,
4. type and time of compaction,
5. environmental conditions during and immediately after construction,
6. length of interval between end of construction and trafficking, and
7. improper embedment of the aggregate.

Variation in materials application will produce a variety of problems. Too much or too little asphalt will cause bleeding or aggregate loss, respectively. Low aggregate application will cause bleeding because free asphalt remains on the surface. Too much aggregate may cause windshield damage and/or may be thoroughly swept from the surface. Thus, to achieve superior seal coat performance, proper and uniform applications of the asphalt and aggregate need to be carefully controlled during construction.

### 4.5 ENVIRONMENTAL CONDITIONS

Environmental conditions have a significant impact on seal coat performance. Favorable conditions must occur during construction and during the period right after construction to ensure superior seal coat performance Precipitation, high winds, and low surface temperature are detrimental to proper adhesion and retention of the aggregate. Cool, wet weather during or right after construction often results in aggregate loss when the surface is first exposed to traffic.

To ensure reasonable environmental conditions, seal coat construction should not occur when the ambient air temperature is 15°C and falling. Construction may commence when the temperature is 10°C and rising. However, seal coat construction using latex-modified binders is more sensitive to environmental conditions and, therefore, the construction temperature limits should be increased to 25° and 20°C, respectively.

It must be remembered that relying on existing temperatures is not sufficient to ensure a successful project. Consideration should also be given to the temperature of the roadway surface on which the seal coat is to be placed.

### 4.6 TRAFFIC CONDITIONS

The effect of traffic on seal coat performance is manifested in two ways. First, during and immediately after placement, there is a normal period when no traffic is allowed on the freshly placed mat. This period ranges from 30 minutes to several hours. The length of time required for delaying traffic depends largely on the functional classification of the roadway being sealed. Relatively high traffic volume facilities may necessitate shorter closure periods. Sufficient time should be allowed for the bond to develop between the binder and the aggregate before normal-speed traffic is allowed on the road. Otherwise, there will be the potential for both aggregate loss and bleeding.

While the most consequential effects of traffic are evident in a short time frame, there is also the long-term effect of traffic. As the asphalt ages and becomes brittle, the minor movement of aggregates under traffic may cause fracture of the asphalt or of the asphalt-aggregate bond and result in aggregate loss.

## 4.7 RECOMMENDATIONS

The primary purpose of this report was to summarize the analysis and evaluation of the use of PG-graded asphalt for seal coats. The adoption of the PG grades will obviate the need to continue the viscosity and/or penetration grades and will begin a specification system based on performance. Thus, the recommendations include the following:

1. The recommended selection criteria for the asphalt binder using the new PG Superpave grading system are based on high and low pavement design temperatures and on traffic levels. Figures__ through __ should be used to determine the proper PG grade of asphalt to be utilized in the various areas of the state. It is recognized that these recommendations may need to be adjusted as indicated by additional field experience.
2. Field personnel should evaluate the recommended PG grades in their region of the state to determine whether the grades are satisfactory.
3. Asphalt cements that must be heated to a temperature in excess of 190°C in order to spray should, instead, be emulsified.
4. Recommendations contained in Appendix B should be followed to maximize the probable success of the seal coat.
5. The contractor must submit a seal coat design for approval prior to beginning construction of the seal coat.
6. It is noted that:

    a. The cold temperatures are surface temperatures assuming that the surface temperatures are equal to the ambient air temperature. The high temperatures are those 20 mm below the surface and are estimated using the Superpave algorithm. Thus, these defined temperatures were used to establish the temperature regimen shown in the map figures. Ultimately, it may be necessary or desirable to redefine the temperatures for the purpose of specifying asphalt binders for seal coats.

    b. None of the Superpave binder test procedures address the very real problem of short-term aggregate loss due to incompatibility between the asphalt binder and aggregate. It is possible that another SHRP product (e.g., the net adsorption, desorption test) could be used to address this issue; however, no testing was accomplished under this project to assess this hypothesis.

These conditions should be addressed in follow-up evaluations of the use of the PG-grading system.

## REFERENCES


1. Introduction to Asphalt, Manual Series No. 5 (MS-5), Asphalt Institute, Inc., Lexington, Kentucky, Eighth Edition, October 1993.

2. T. W. Kennedy, G. A. Huber, E. T. Harrigan, R. J. Cominsky, C. S. Hughes, H. L. Von Quintus, and J. S. Moulthrop, "Superior Performing Asphalt Pavements (Superpave): The Product of the SHRP Asphalt Research Program," Strategic Highway Research Program, SHRP-A-410, 1994.

3. *FOCUS,* June/July 1996, Federal Highway Administration.

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5. Standard Test Methods for Emulsified Asphalts, Designation D244-84, American Society for Testing and Materials, Volume 4.03, Philadelphia, Pennsylvania.

6. Texas Department of Transportation, Materials and Tests Division Manual of Testing Procedures.

7. Asphalt Surface Treatments and Asphalt Penetration Macadam, Manual Series No. 13 (MS-13), The Asphalt Institute, College Park, Maryland, August 1979.

8. Standard Specifications for the Construction and Maintenance of Highways, Streets, and Bridges, Texas Department of Transportation, 1995.

## APPENDIX A.
## SUPERPAVE BINDER SPECIFICATION (AASHTO MP1)

# Performance Graded Binder Specification

| Performance Grade | PG 52 | | | | | | | PG 58 | | | | | PG 64 | | | | | PG 70 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | -10 | -16 | -22 | -28 | -34 | -40 | -46 | -16 | -22 | -28 | -34 | -40 | -16 | -22 | -28 | -34 | -40 | -10 | -16 | -22 | -28 |
| Average 7-day Maximum Pavement Design Temperature, °C [a] | <52 | | | | | | | <58 | | | | | <64 | | | | | <70 | | | |
| Minimum Pavement Design Temperature, °C [a] | >-10 | >-16 | >-22 | >-28 | >-34 | >-40 | >-46 | >-16 | >-22 | >-28 | >-34 | >-40 | >-16 | >-22 | >-28 | >-34 | >-40 | >-10 | >-16 | >-22 | >-28 |
| Original Binder | | | | | | | | | | | | | | | | | | | | | |
| Flash Point Temp, T48: Minimum °C | 230 | | | | | | | | | | | | | | | | | | | | |
| Viscosity, ASTM D 4402: [b] Maximum, 3 Pa·s (3000 cP), Test Temp, °C | 135 | | | | | | | | | | | | | | | | | | | | |
| Dynamic Shear, TP5: [c] G*/sin δ, Minimum, 1.00 kPa Test Temperature @ 10 rad/s, °C | 52 | | | | | | | 58 | | | | | 64 | | | | | 70 | | | |
| Rolling Thin Film Oven (T240) or Thin Film Oven (T179) Residue | | | | | | | | | | | | | | | | | | | | | |
| Mass Loss, Maximum, % | 1.00 | | | | | | | | | | | | | | | | | | | | |
| Dynamic Shear, TP5: G*/sin δ, Minimum, 2.20 kPa Test Temp @ 10 rad/sec, °C | 52 | | | | | | | 58 | | | | | 64 | | | | | 70 | | | |
| Pressure Aging Vessel Residue (PP1) | | | | | | | | | | | | | | | | | | | | | |
| PAV Aging Temperature, °C [d] | 90 | | | | | | | 100 | | | | | 100 | | | | | 100(110) | | | |
| Dynamic Shear, TP5: G*sin δ, Maximum, 5000 kPa Test Temp @ 10 rad/sec, °C | 25 | 22 | 19 | 16 | 13 | 10 | 7 | 25 | 22 | 19 | 16 | 13 | 28 | 25 | 22 | 19 | 16 | 34 | 31 | 28 | 25 |
| Physical Hardening [e] | Report | | | | | | | | | | | | | | | | | | | | |
| Creep Stiffness, TP1: [f] S, Maximum, 300 MPa m-value, Minimum, 0.300 Test Temp, @ 60 sec, °C | 0 | -6 | -12 | -18 | -24 | -30 | -36 | -6 | -12 | -18 | -24 | -30 | -6 | -12 | -18 | -24 | -30 | 0 | -6 | -12 | -18 |
| Direct Tension, TP3: [f] Failure Strain, Minimum, 1.0% Test Temp @ 1.0 mm/min, °C | 0 | -6 | -12 | -18 | -24 | -30 | -36 | -6 | -12 | -18 | -24 | -30 | -6 | -12 | -18 | -24 | -30 | 0 | -6 | -12 | -18 |

**Notes:**

a. Pavement temperatures can be estimated from air temperatures using an algorithm contained in the SUPERPAVE software program or may be provided by the specifying agency, or by following the procedures as outlined in PPX.

b. This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

c. For quality control of unmodified asphalt cement production, measurement of the viscosity of the original asphalt cement may be substituted for dynamic shear measurmeents of G*/sin δ at test temperatures where the asphalt is a Newtonian fluid. Any suitable standard means of viscosity measurement may be used, including capillary or rotational viscometry (AASHTO T 201 or T 202).

d. The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures 90° C, 100° C or 110° C. The PAV aging temperature is 100° C for PG 58- and above, except in desert climates, where it is 110° C.

e. Physical Hardening - TP 1 is performed on a set of asphalt beams according to Section 13.1, except the conditioning time is extended to 24 hrs ± 10 minutes at 10° C above the minimum performance temperature. The 24-hour stiffness and m-value are reported for information purposes only.

f. If the creep stiffness is below 300 MPa, the direct tension test is not required. If the creep stiffness between 300 and 600 MPa the direct tension failure strain requirement can be used in lieu of the creep stiffness requirement. The m-value requirement must be satisfied in both cases.

# APPENDIX B.
# RECOMMENDED GUIDELINES AND INFLUENCING FACTORS FOR SEAL COATS

# APPENDIX B.
# RECOMMENDED GUIDELINES AND INFLUENCING FACTORS FOR SEAL COATS

## B.1. INFLUENCING FACTORS

The characteristics of asphalt binder materials in performance-based specifications are just a part of many influencing factors. It became apparent that numerous other factors often influence the performance of seal coats. Thus, it is obvious that one should consider all of the other factors when specifying, designing, and constructing a seal coat. For example, a seal coat placed in cool, wet weather may perform poorly due to the obvious cause of unfavorable environmental conditions. Binder properties cannot overcome poor construction conditions. The two major types of distress possible with seal coats are *bleeding* and *aggregate loss*. These are discussed in greater detail later in this chapter under Article B.2.

These guidelines present an overview of all factors that were identified as influential to seal coat performance.

The technical literature, as well as interviews with TxDOT engineers and other knowledgeable individuals, indicated that the success of seal coats is influenced by the following factors:

1. quality of design,
2. quality and consistency of construction,
3. quality and consistency of materials,
4. environmental conditions, and
5. traffic conditions.

### Quality of Design

The product of a seal coat design is an optimized rate of application of asphalt material and aggregate. Asphalt application rate is designed in terms of liters of product per square meter. Aggregate application is designed and specified in two ways: on the basis of mass spread rate (kilograms per square meter) or on the basis of a volumetric spread ratio (square meters per cubic meter). TxDOT normally specifies aggregate application using the volumetric spread ratio method.

The most widely used design procedures are traceable to the one originally developed by Kearby (1), which has been modified and updated by various agencies and researchers. Hveem et al. also published an early seal coat design method (2). Currently, the most widely distributed design guidelines in the U.S. are those developed by Lovering of the Asphalt Institute (3, 4), which are based primarily on work by Hanson (5), but also on work performed by McLeod (6, 7), and Benson et al. (8). Another execution of the Kearby method was reported by Monismith (9) although this method also appears to be heavily influenced by Lovering.

Epps et al. (10) reported that the most common design procedure used by TxDOT prior to 1980 was the Kearby approach, which was then called the "board method." They also reported another method, a modified Kearby approach, developed by J. W. Livingston of the Atlanta District. In their comparison of the field performance resulting from the various design methodologies, Epps et al. indicated that the modified Kearby approach developed by Livingston resulted in the best aggregate application rate. The Lovering and Livingston-modified Kearby method resulted in the best asphalt application rate.

A seal coat design should be mandatory; nevertheless, seal coats are seldom rigorously designed in Texas or elsewhere. The bulk of the seal coat design research in the U.S. was performed in the middle 1940s through the early 1960s. That research provided the necessary tools for TxDOT and other engineers to effectively establish the proper quantities of asphalt and aggregate materials, which generally do not change in a particular geographic area. Once effective quantities were established, specifiers tended to stick with application rates known to work. Nevertheless, the input parameters to the design procedures still form an important list of factors that must be considered when designing a suitable seal coat and evaluating the seal coat performance.

Each of the design methods is aimed at developing the proper asphalt binder and aggregate application rates. They variously consider the following factors:

1. traffic level;
2. the top size, gradation, bulk specific gravity, and loose unit weight of aggregate;
3. the type of asphalt material (i.e., asphalt cement versus asphalt emulsion);
4. the condition of the existing surface (dry, oxidized versus flushed);
5. desired aggregate embedment depth; and
6. in the case of multiple applications, the number of layers.

The following generalized equations are evident from the various design approaches:

$$\text{Asphalt Application Rate} = f(1/T, E, S, A, 1/R)$$

where

T = traffic factor,

E = aggregate embedment,

S = correction for condition of existing surface,

A = factor related to aggregate size, shape, gradation, durability, and porosity, and

R = residual asphalt content of binder (i.e., for asphalt cements R = 1.00).

Aggregate Application Rate = *f*(G, U, W)

where

G = average aggregate size,

U = aggregate loose unit weight, and

W = aggregate wastage factor.

Traffic level influences asphalt application rate. In all of the methods, design traffic parameters decrease the application rate for higher volume pavements and increase the application rate for lower volume pavements. Table B.1 shows traffic factors established by the Asphalt Institute (3). Observing these values indicates that traffic level must be considered to achieve superior seal coat performance.

*Table B.1. Typical traffic factors for seal coat design (3)*

| Aggregate | Traffic Factor = Percentage (expressed as a decimal) of 20 percent void space in cover aggregate to be filled with asphalt | | | | |
|---|---|---|---|---|---|
| | Traffic, vehicles per day | | | | |
| | Under 100 | 100 to 500 | 500 to 1000 | 1000 to 2000 | Over 2000 |
| Recognized Good Type of Aggregate | 0.85 | 0.75 | 0.70 | 0.65 | 0.60 |

Aggregate embedment is quantified in two ways, either in terms of a percentage of average seal coat thickness in the wheelpath or more simply, as the visual observation of percentage embedment of aggregate with respect to maximum size. In the latter case, Epps et al. (10) reported values ranging from 7 to 100 percent for 60 projects analyzed. In that study, it was concluded based on the consensus of the researchers' visual observations, that 80 percent embedment was reasonable from the standpoint of bleeding.

A common factor in the technical literature and in discussions with TxDOT personnel is that asphalt application rates must be adjusted for the existing surface condition to achieve superior seal coat performance. Table B.2 shows surface correction factors attributed to Hanson (5). Considering that typical asphalt cement application rates are in the range from about 0.9 to 1.4 liters per square meter, the adjustment values shown in Table B.2 are quite significant. At a very high level of existing surface demand, it becomes impractical from a construction standpoint to increase the application rate to account for surface absorption. In those instances where high surface correction factors seem necessary, it may be necessary to consider action such as a fog seal prior to the seal coat to satisfy surface demand for asphalt.

*Table B.2. Asphalt application adjustment rates to account for surface condition (5)*

| Surface Condition | Adjustment Factor, $l/m^2$ |
|---|---|
| Smooth, non-porous surface | 0.00 |
| Slightly porous, slightly oxidized surface | +0.14 |
| Slightly pocked, porous, oxidized surface | +0.28 |
| Badly pocked, porous, oxidized surface | +0.42 |
| Flushed asphalt surface | -0.14 |
| Note: + indicates add asphalt, - indicates subtract asphalt | |

Most of the literature surveyed applies adjustments on the basis of bulk surface condition with no accounting for localized differences in surface demand. A variation of this approach was developed and reported by Schulz and Russell (11) in the Brownwood District where lateral adjustments were made to application rates to account for typically lesser amounts of asphalt needed in the wheelpaths and greater amounts needed between the wheelpath. The lateral adjustment in application rate was facilitated by using asphalt distributor spray bar nozzles with differing orifice size.

Epps et al. (10) reported using a "putty method" to estimate the "surface hunger" for asphalt. Using this procedure, surface texture measurements were performed on 120 roadway sites. These measurements showed an average difference in surface texture of 0.254 cubic millimeters per square millimeter when comparing wheelpath with between-wheelpath texture. They suggested this would result in a difference of 0.28 liters per square meter.

Important aggregate factors that need to be considered for superior seal coat performance are aggregate size, shape, gradation, durability, porosity, and cleanliness. Aggregate size is a design factor to the extent that it affects the amount of asphalt in terms of a desired embedment depth. Larger aggregates require more asphalt to achieve a prescribed embedment depth.

Aggregate shape is a critical factor because most of the design methods assume aggregate is largely cubical. The design method outlined by the Asphalt Institute (3) adjusts for aggregate shape by means of a parameter called "flakiness index." The flakiness index of an aggregate is determined from a test method that uses a special set of slotted sieves. It is used to estimate the average least dimension of the aggregate, which in turn, is used to compute required asphalt application rate. A flaky aggregate (i.e., flat and/or elongated) results in a lower asphalt application rate since its average least dimension is smaller. Consequently, less asphalt is needed for a desired embedment depth. Even if properly taken into account using an approach such as the Asphalt Institute method (3), flaky aggregates pose difficulties with seal coats because they do not orient themselves in their least dimension during construction. It was reported in discussions with TxDOT personnel that flaky aggregates tend to "roll over" under traffic, thus decreasing the effective mat thickness; the net effect of this action is to promote wheelpath bleeding and a lack of adequate surface friction to the roadway surface (which often results in a seal coat inadequate for its designed purpose). Flaky aggregate is also prone to degradation, which reduces the aggregate size. The net result of degradation is also bleeding. In recognition of these problems, some districts that have sources of flaky aggregate (e.g., Corpus Christi and Dallas) have placed a maximum limit on flakiness index for seal coat aggregate. A typical maximum flakiness index is about 16. TxDOT (Tex-224-F) (13) has a test to measure this parameter. Specifying high quality aggregate in this manner is probably the best approach to dealing with the effect of aggregate shape.

Aggregate gradation influences seal coat design and performance in three ways: maximum size, well graded versus uniformly graded, and dust content. Aggregates with larger average particle size require a higher application rate for a desired embedment depth. Most agencies have abandoned the well graded aggregate in favor of uniformly graded aggregate for seal coats. Table B.3 shows the master gradation ranges of the most common seal coat aggregates used in Texas (12). The distribution of particle sizes clearly illustrates that TxDOT specifies uniformly graded aggregate.

*Table B.3. TxDOT gradation requirements for seal coat aggregate (12)*

| Size, mm | Grade 3 | Grade 4 | Grade 5 |
|---|---|---|---|
| 19 | 0 | - | - |
| 16 | 0 - 2 | 0 | - |
| 12.5 | 20 - 40 | 0 - 2 | 0 |
| 9.5 | 80 - 100 | 20 - 35 | 0 - 5 |
| 6.3 | 95 - 100 | - | - |
| 4.75 | - | 95 - 100 | 40 - 85 |
| 2.00 | 99 - 100 | 99 - 100 | 98 - 100 |
| 0.850 | - | - | 99 - 100 |
| Note: Values are percent retained on sizes shown. | | | |

In general, uniformly graded cover aggregates are advantageous because they tend to be cleaner, do not tend to segregate in stockpiles or during handling, and result in a quieter ride (3) when compared to graded aggregates. Graded cover aggregates tend to require less asphalt and are less expensive than uniformly graded aggregate, which means that graded aggregate seal coats are less expensive in terms of first cost. Evidently, the performance and other advantages of uniformly graded aggregate outweigh the low first cost advantages of graded aggregate.

The amount of dust (percent finer than 75 microns) contained by the aggregate affects seal coat performance. In the literature, there appears to be no consensus regarding the proper amount of dust in the cover aggregate. However, it was noted in at least two references (3, 14) and also in conversations with TxDOT personnel that overly dusty aggregates were undesirable because the dust tends to disturb the bond between the asphalt and aggregate. TxDOT specifications (12) require no greater than 1.0 percent by weight of fine dust, clay-like particles and/or silt.

Aggregate toughness and durability play a role in seal coat performance because of their effect on aggregate size. If aggregates degrade when manipulated during construction or under traffic, they are effectively reduced in size; bleeding, aggregate loss, or loss of surface friction can be the result.

The effect of aggregate porosity on seal coat performance is analogous to that resulting from existing surface condition. Highly absorptive aggregates require an increase in application rate to satisfy their asphalt demand. Some TxDOT districts (e.g., Abilene, Lubbock, and Pharr) specify precoated seal coat aggregate, which in effect, satisfies this demand of the aggregate for asphalt binder. Another benefit of precoated aggregate is that during the precoating operation, dust is removed or compensated. The Ft.Worth District sometimes fog seals the travel lanes of recently completed seal coats. This novel approach satisfies additional aggregate demand for asphalt and may facilitate safety by providing contrasting delineation between shoulders and travel lanes.

Properly accounting for the residual asphalt content of the emulsion sealing grade binders is necessary in achieving superior seal coat performance. The design methods examined generally accounted for residual asphalt content by dividing the application rate for asphalt cement by the asphalt residue in emulsions. For example, if a seal coat design resulted in an application rate of 1.15 liters per square meter for an asphalt cement, then the proper amount of emulsion to be used would be 1.15/0.65 or 1.77 liters per square meter. This calculation is based on the mass percentage of asphalt residue in sealing grade emulsions, which is typically 65 percent. Epps et al. (10) suggest that the adjusted application rate to account for residual asphalt content be further adjusted by a factor of 0.80. In the previous example, the design application rate for an asphalt emulsion then would be 1.77×0.8 or 1.42 liters per square meter.

In summary, selecting the proper asphalt binder, durable aggregate with proper size, gradation, and shape (preferably cubical), and application rates of both the asphalt binder and the aggregate is to ensure optimum embedment of aggregates in the asphalt binder for the project traffic and surface conditions all critical in the design. Insufficient embedment results in aggregate loss while too deep embedment results in bleeding. Based on observed field performance (10), it is desirable to have less than about 80 percent of the height of the aggregate covered with the binder.

*Quality of Construction*

As with other construction materials, quality of construction plays a very significant role in the performance of seal coats. There appears to be consensus that selection of the best material and the best design approach cannot compensate for poor workmanship. As evidence, a consistent theme in interviews with TxDOT personnel indicated that construction, rather than material deficiencies, were the single biggest cause of poor performing seal coats. The following factors are some of the construction variables cited by TxDOT personnel and in the technical literature that influence performance of seal coats:

1. longitudinal and transverse variation in the rates of material application,
2. length of time between application of binder and application of aggregate,
3. variation in materials,
4. type and time of compaction,
5. environmental conditions during and immediately after construction,

6. length of interval between end of construction and trafficking, and,
7. improper embedment of the aggregate.

Variation in materials application causes a variety of problems. Obviously, if too much or too little asphalt is applied, bleeding and aggregate loss, respectively, can result. Low aggregate application, in effect, will cause bleeding because free asphalt remains on the surface. Too much aggregate applied may cause windshield damage if not thoroughly swept from the surface. Clearly, to achieve superior seal coat performance, variation in material application rates needs to be minimized.

TxDOT and most other agencies do not control seal coat construction in the same manner as higher type surfaces such as asphalt concrete. Instead of measuring in-place seal coat compositional properties, application rates are monitored by carefully measuring quantities used over the length and width of application. The following equations (4, 14) are used to compute asphalt application rates:

$$R = \frac{T \times M}{W \times L}$$

where

R = rate of asphalt application, liters/square meter,
T = total volume applied in liters,
W = width of spread in meters,
L = length of spread in meters, and
M = multiplier to correct asphalt volume to basis of 15.6°C.

$$R = \frac{A}{W \times L}$$

where

R = rate of aggregate application in kilograms/square meter,
A = mass of aggregate used in kilograms,
W = width of spread in meters, and
L = length of spread in meters.

For aggregate spread ratio, the following equation is used:

$$SR = \frac{U}{R}$$

where

SR = spread ratio in square meters per cubic meter,

R = rate of aggregate application in kilograms/square meter, and

U = loose unit weight of aggregate in kilograms per cubic meter.

The volume of asphalt material used (T in the above equation) is measured by "strapping" distributors before and after each application. A strapping rod is a calibrated dipstick that is inserted into a distributor tank to accurately measure the amount of material in the tank. Aggregate use (A in the above equation) is quantified by counting loads of aggregate hauled by trucks of known volume or mass. This approach is necessary and ideal for pay purposes, and diligence on the part of the inspector and contractor will minimize longitudinal variation. However, it does not tend to highlight transverse fluctuations in application.

Transverse variation in asphalt application rate causes a surface condition called streaking. This is manifested by longitudinal striations that, upon close examination, exhibit alternating patterns of lean and heavy strips of asphalt. The Asphalt Institute (4) cites the following causes of streaking:

1. improper spray bar height,
2. spray bar rising as distributor tank empties,
3. improper angle on one or more nozzles,
4. plugged nozzles,
5. wrong pump speed,
6. asphalt material too viscous, and
7. spray pressure too low due to worn or poorly maintained pump.

Figure B.1 (4) illustrates a generalized view of spray bar geometry. It is clear from this figure that proper nozzle angle and height are critically important in achieving proper transverse application rates.

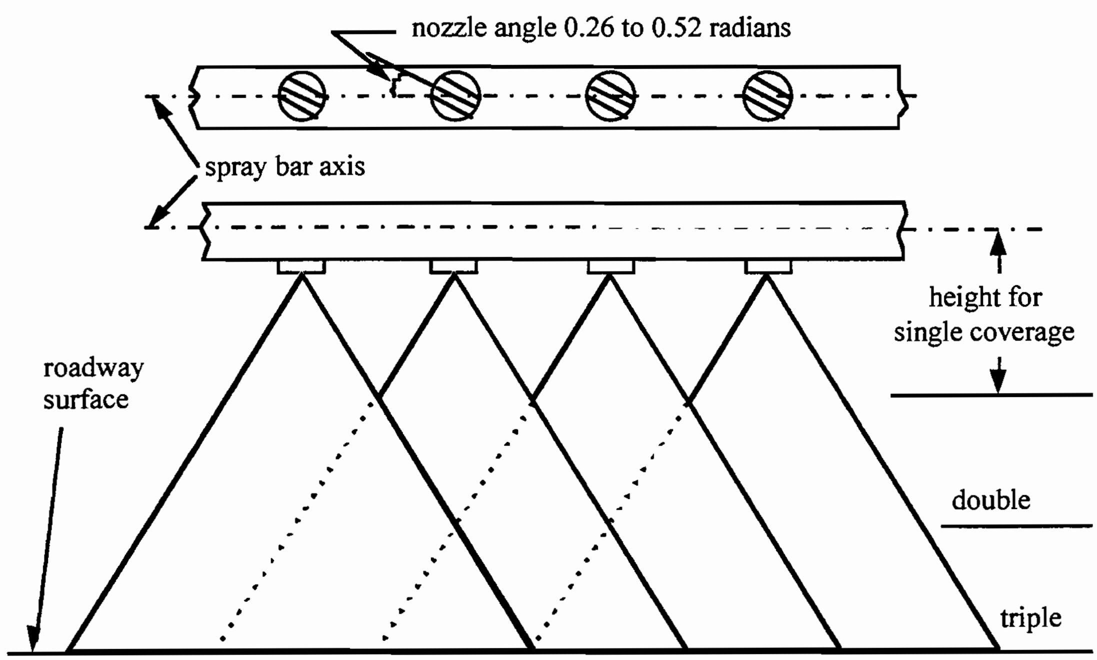


*Figure B.1. Spray bar geometry (4)*

In the Brownwood District, Schulz and Russell (11) measured extraordinary variation in transverse application of asphalt. Of 35 spray nozzles they tested, only 9 were shown to be within 10 percent of the desired spray width. Their applied research resulted in a test to accurately measure spray width of nozzles. They also developed a "bucket test" to check the amount of asphalt delivered by each nozzle. Their test was subsequently standardized (Tex-922-K) (13) for general use in calibrating distributors on TxDOT projects. In addition to Shulz and Russell's method, ASTM provides a procedure for spot checking longitudinal as well as transverse application rate (15). The ASTM procedure, originally developed by Zube (16) of the California Department of Transportation, utilizes absorbent cotton pads to measure variation in application rate.

The length of time between application of binder and application of aggregate affects the performance of seal coats. If aggregate is applied when the binder is too viscous, proper aggregate embedment and adhesion are not achieved. The result is aggregate loss. In the case of asphalt cement binders, viscosity is governed completely by temperature assuming contamination is not an issue. Thus, aggregate must be applied immediately after application of the binder. In the case of asphalt emulsion binders, viscosity is governed primarily by the characteristics of the particular emulsion system and secondarily by temperature. If an emulsion is allowed to break (water evaporates from system and asphalt droplets coalesce) the viscosity of the residual asphalt will be too high to facilitate proper embedment and adhesion. Evidently, regardless of binder type, it is imperative that aggregate be spread as soon as practically possible after application of binder or aggregate loss may result.

*Quality and Consistency of Materials*

Undue variation in project materials can cause a variety of problems. Variation in amount and type of dust can cause alternating fat and lean spots as well as aggregate loss. If aggregate size varies above and below the design value, asphalt application rate is alternatively too little and too much. One of the advantages of TxDOT's approach of using single-size seal coat aggregates is that the aggregates do not segregate during handling. This considerably reduces problems caused by variation in aggregate size.

To maintain a consistent sprayed binder film thickness, binder viscosity must be kept as constant as possible. Binders that are too viscous do not allow aggregate to be properly embedded or wetted with a resulting loss of aggregate and free asphalt on the surface. Binders that are too thin flow excessively and form too thin of a surface film to achieve proper embedment. This also results in aggregate loss and free asphalt on the surface. Figure B.2 illustrates these extremes.


*Figure B.2. Effect of binder viscosity on aggregate embedment*

For these reasons, TxDOT and other agencies carefully control application temperature. When asphalt cements are used for spray applications, a viscosity in the range from 0.020 to 0.120 Pa·s is recommended by Asphalt Institute (3). A previous version of TxDOT specifications (17) required a more restrictive viscosity range of 0.10 to 0.12 Pa·s. Current specifications (12) place spray temperature requirements and further state that the actual spray temperature must not vary more than 8° C from the specified temperature. Table B.4 shows TxDOT (12) application temperature requirements for the most common sealing grade binders.

*Table B.4. Application temperature requirements (12)*

| Binder | Application Temperature, °C | |
|---|---|---|
| | Recommended | Maximum Allowable |
| AC-5 or 10 | 135 - 180 | 190 |
| AC-5 or 10 + 2% SBR | 145 - 190 | 200 |
| AC-10 + 3% SBR | 150 - 180 | 180 |
| RS-2, RS-2h, CRS-2, CRS-2h, CRS-2P, HFRS-2, HFRS-2P | 45 - 70 | 80 |

Sealing grades of asphalt emulsions are necessarily precarious systems. Their formulation represents a compromise between two extremes. They must remain stable enough to survive transport, short term storage, spraying, and aggregate embedment, and yet sufficiently unstable so that they will immediately begin to break and set after aggregate is applied and rolled. Emulsion systems that satisfy these requirements possess viscosity characteristics that are influenced by many factors in addition to temperature. Unlike asphalt cements, other factors that influence viscosity must be considered when using asphalt emulsions. In general, overheating, underheating, excessive handling and pumping, and improper storage are factors that will cause viscosity problems with asphalt emulsions. The Asphalt Institute (4) provides a comprehensive list of "do's" and "don'ts" with respect to proper storage and handling of asphalt emulsions. The effect of improper viscosity when using asphalt emulsions is the same as with asphalt cement, aggregate loss, and free asphalt on the surface.

Rolling is one of the last important steps in proper seal coat construction. The purpose of rolling is twofold (4): to completely force the aggregate into the binder film and to orient the aggregate into a dense mass approaching the typical design air void content of 20 percent. There seems to be general consensus that pneumatic tired rollers are preferable because unlike steel wheeled rollers, they do not bridge surface irregularities and do not degrade the aggregate. Occasionally, pneumatic tired rollers cause aggregate pick up problems and for that reason, some engineers specify the use of steel-wheeled rollers. However, it is possible that when pick up problems occur, it is an indication of a more fundamental problem related to binder or aggregate application rate, flaky aggregate, material variability, or all of these. There is also general consensus that rolling should begin as soon as practically possible after application of aggregate. If too much time expires before rolling, the binder viscosity may be too high to facilitate thorough embedment.

### *Environmental Conditions*

Environmental conditions were often cited by TxDOT and other personnel as having significant impact on seal coat performance. Evidently, to achieve superior seal coat performance, favorable conditions must occur in two critical periods: during construction and during the period right after construction upon early exposure to traffic. Precipitation, high winds, and low surface temperature are detrimental to proper adhesion and retention of the aggregate. Arrival of cool, wet weather during or right after construction often results in aggregate loss when the surface is first exposed to traffic.

To ensure reasonable environmental conditions, TxDOT specifications (12) require that seal coat construction not occur when the ambient air temperature is 15°C and falling. Construction may commence, however, when the temperature is 10°C and rising. Evidently, seal coat construction using latex modified binders is more sensitive to environmental conditions because TxDOT's specifications raise the these limitations to 25°C and 20°C, respectively. An additional TxDOT requirement when using latex modified binders is that the surface temperature must be greater than 20°C.

The long-term performance of a seal coat can also be influenced by extraordinary weather events. An extended period of unusually hot weather can cause bleeding as well as accelerated aging. Extended cold weather can result in brittleness of the aged binder and lead to aggregate loss and cracking.

### *Traffic Conditions*

The effect of traffic on seal coat performance is manifested in two ways. First, during and immediately after placement, there is a normal period when no traffic is allowed on the freshly placed mat. This period ranges from 30 minutes to several hours. The length of time with no traffic depends largely on the functional classification of the roadway being sealed. Relatively high traffic volume facilities necessitate shorter closure periods. Many engineers believe that sufficient time should be allowed for the bond to develop between the binder and the aggregate before normal speed traffic is allowed on the road. Otherwise there will be potential for both aggregate loss and bleeding. According to one source (4) this period is 24 hours with traffic speeds no greater than 30 kilometers per hour. While this may be impractical for certain facilities, there are remedial measures that may be employed to control traffic. Pilot vehicles have effectively been used to direct traffic on freshly placed, tender mats. Another effective technique utilizes active and visible law enforcement personnel to control the disposition of vehicles on fresh mats.

While the most consequential effects of traffic are short term in nature, there is also a long-term effect of traffic. As the asphalt ages and becomes brittle, small movement of aggregates under traffic may cause fracture of the asphalt and loss of the aggregate.

## B.2. EFFECT OF ASPHALT BINDERS ON SEAL COAT PERFORMANCE

The first step in development of performance based specifications for seal coat binders is identification of the seal coat distresses which binders influence. Once that has been accomplished, it is possible to establish critical levels of binder properties that will result in favorable performance. There are two major types of distress associated with seal coats: bleeding and aggregate loss.

### *Bleeding*

Bleeding or flushing refers to a condition of the seal coat where the binder has moved upward to the surface creating a layer of asphalt at the top. Air void space, normally assumed to be approximately 20 percent by all the design methods, is greatly reduced. The result is a slick surface with low friction characteristics. This condition is hazardous, particularly during wet weather conditions. The previous section cited many of the causes of bleeding. Assuming that the seal coat design is correct and that aggregate materials and construction are of consistent quality, a binder may contribute significantly to bleeding distress if:

1. it is too soft at the high temperatures to which it is exposed, and
2. it is too soft to rigidly maintain aggregate orientation under the traffic to which it is exposed.

### *Aggregate Loss*

Aggregate loss refers to a condition of the seal coat where traffic dislodges aggregate particles. If sufficient aggregate is removed, free asphalt becomes the wearing surface and hazardous conditions exist. In addition, the loose stones cause vehicle damage. Undue aggregate loss can occur in the short term immediately after construction, or in the long term during the seal coat's service life. Again, assuming that the seal coat design is correct and that aggregate materials and construction are of consistent quality, a binder may contribute significantly to short term aggregate loss if:

1. it is incompatible with the aggregate,
2. it is too soft to retain the aggregate under the mechanical abrasion of early traffic to which it is exposed, and
3. it is too brittle under low temperature conditions during the first winter.

A binder may contribute to long term aggregate loss if:

1. it ages excessively and becomes brittle,
2. it is too brittle under the low temperature conditions to which it is exposed, and
3. a combination of numbers 1 and 2.

From the standpoint of bleeding and short-term aggregate loss, a very stiff, aging-prone binder is favorable. From the standpoint of long-term aggregate loss, a very compliant, non-aging binder is favorable. Thus, to ensure that a binder contributes an equitable share to overall seal coat performance, a compromise must be made. The binder must be stiff enough during its early life so that it does not bleed or suffer early aggregate loss, but not so stiff that long term aggregate loss is excessive. The binder must also be compatible with the aggregate. Test methods and specification criteria must be established to address these desired performance characteristics.

**B.3. SELECTION OF BINDER GRADE**

In order to complete the information necessary to make a satisfactory design for the proposed seal coat and the conditions anticipated to exist during its anticipated life, select the grade of asphalt binder from the following maps shown in the figures below. The grade of asphalt binder together with the project aggregate can now be used to properly design the seal coat and determining application rates, placement temperatures, and construction procedures.

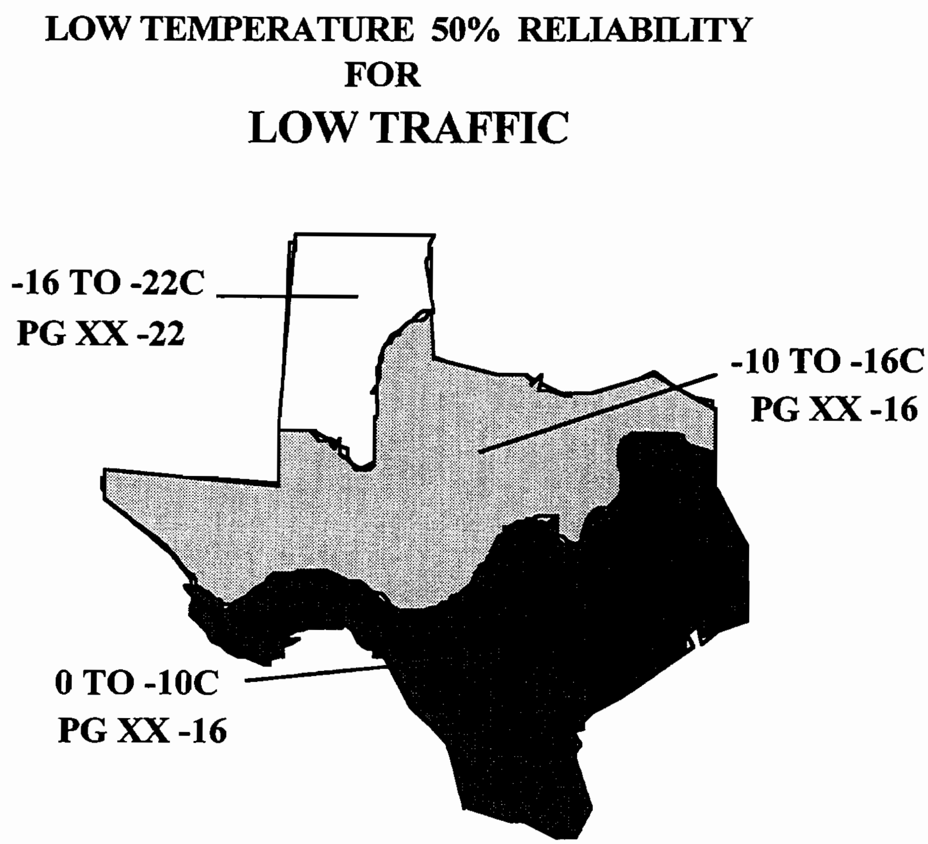


*Figure B.3. Recommended low temperature asphalt binder grades for low traffic and 50% reliability*

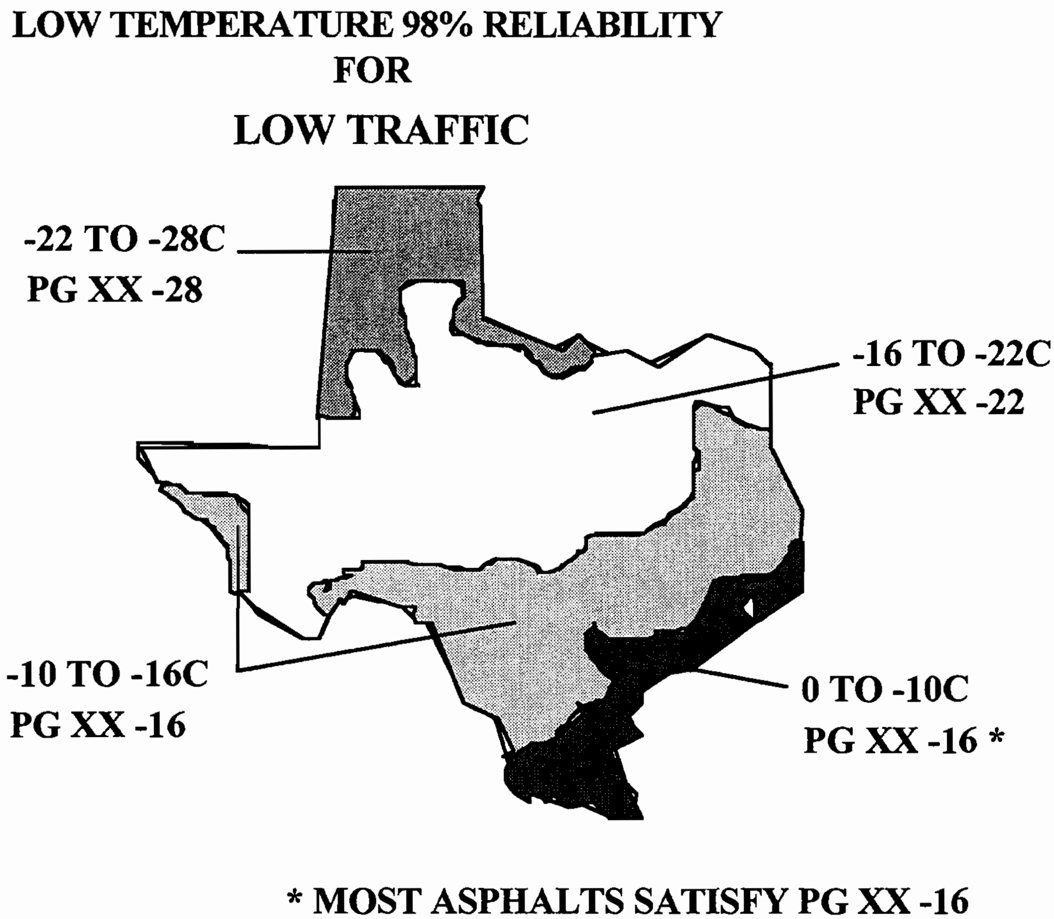


*Figure B.4. Recommended low temperature asphalt binder grades for low traffic and 98% reliability*

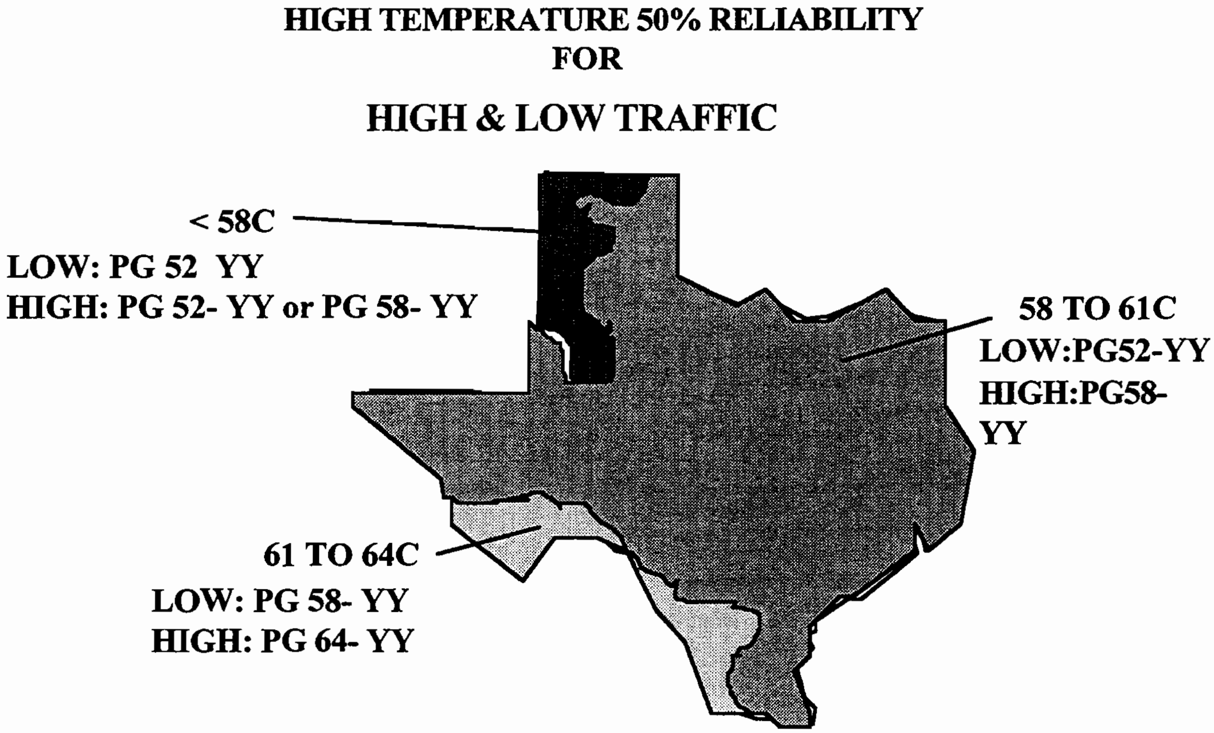


*Figure B.5. Recommended high temperature asphalt binder grades for high and low traffic and 50% reliability*

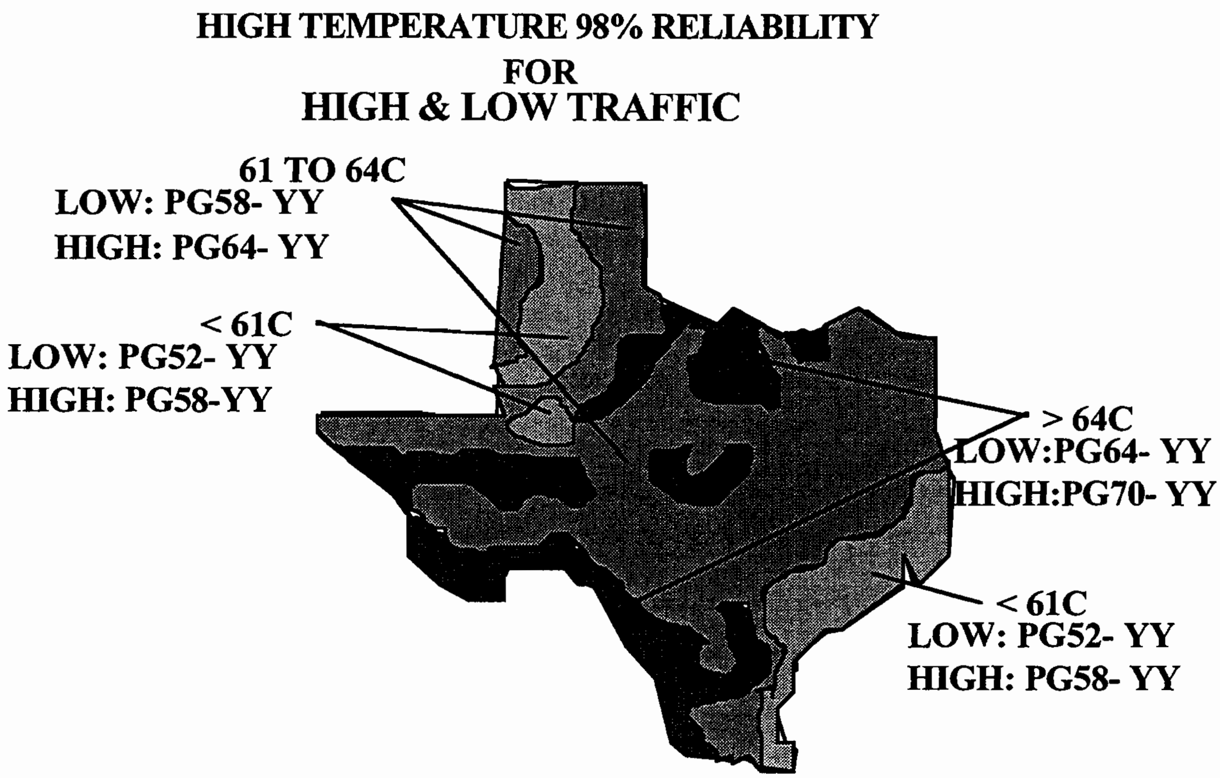


*Figure B.6. Recommended high temperature asphalt binder grades for high and low traffic and 98% reliability*

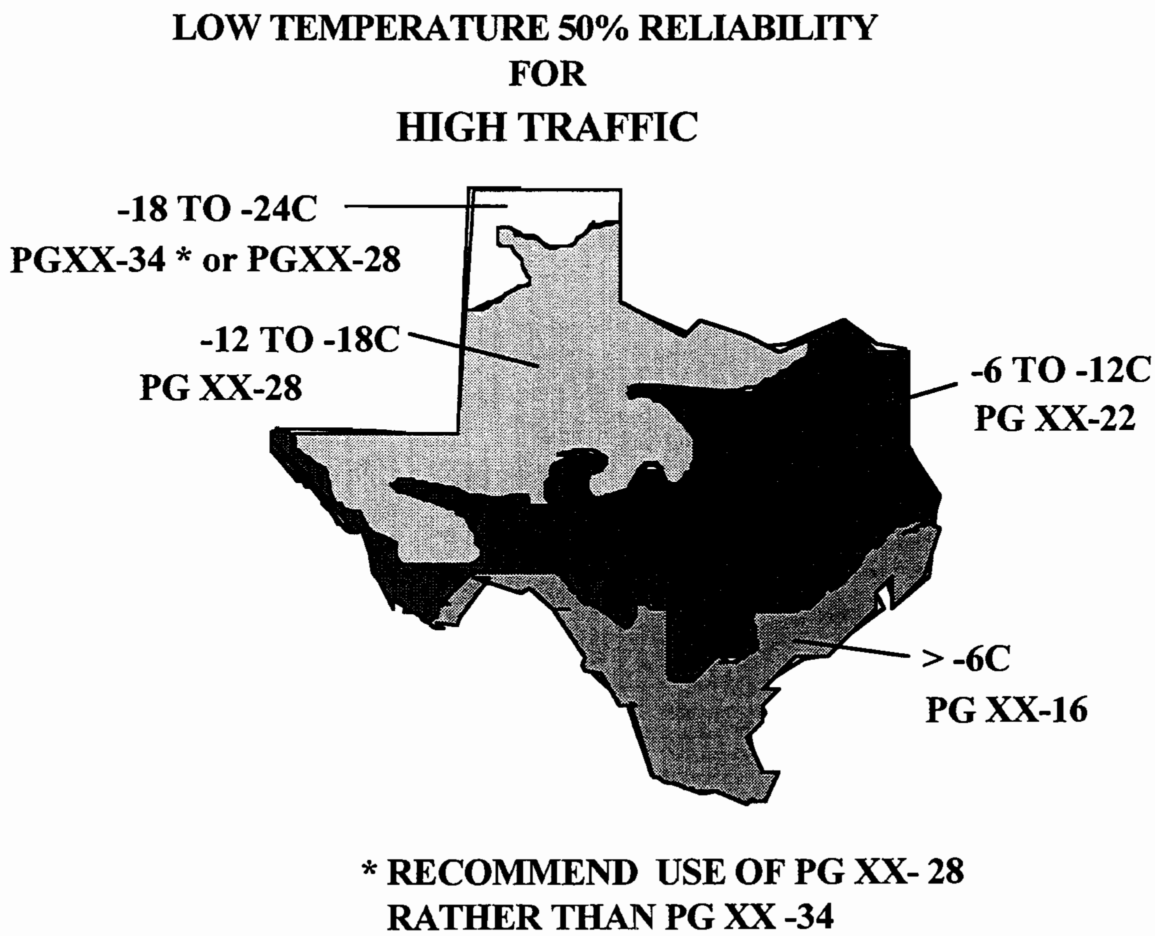


*Figure B.7. Recommended low temperature asphalt binder grades for high traffic and 50% reliability*

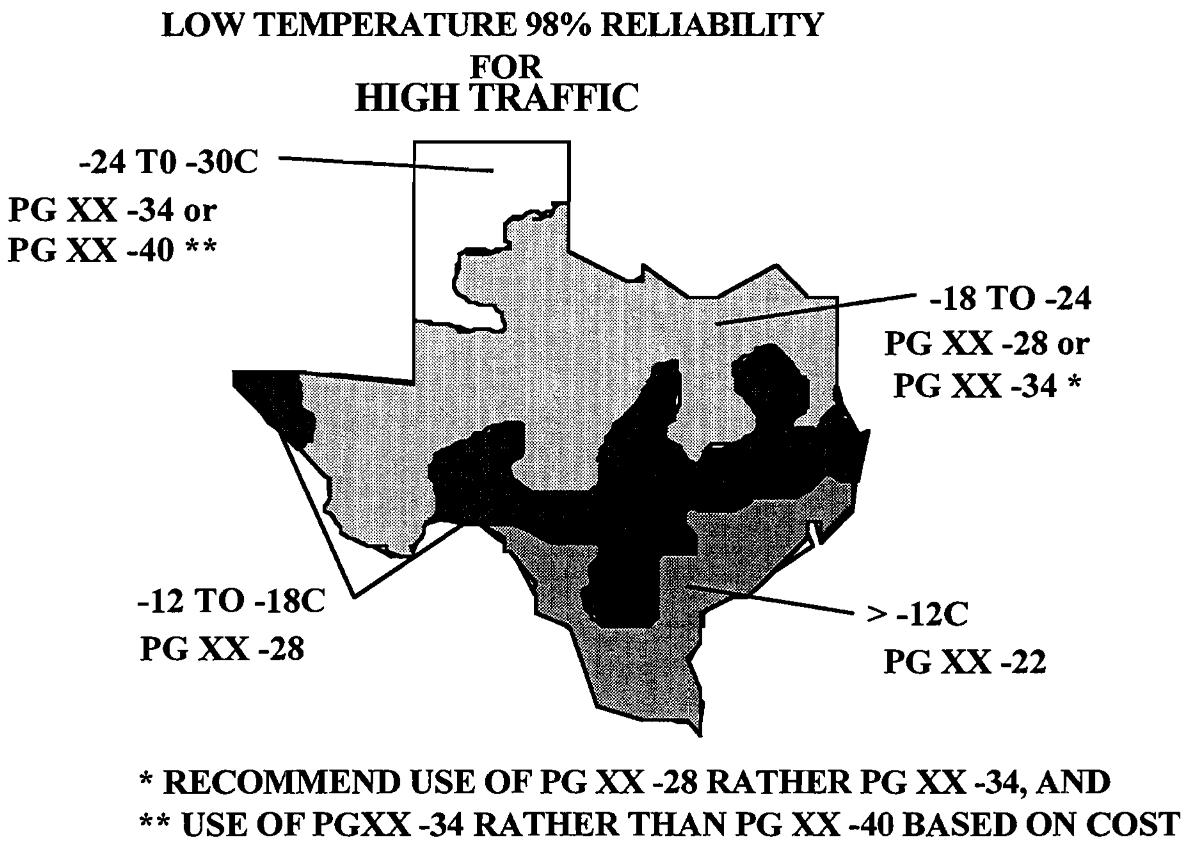


*Figure B.8. Recommended low temperature asphalt binder grades for high traffic and 98% reliability*