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16. Abstract

Presently, surface treatment design and material selection is based on traditional specifications and experience, which are not performance-based and sometimes result in inadequate performance of the surface treatment. In 2000 the first phase of a Texas Department of Transportation (TxDOT) research project developed a surface performance-graded (SPG) specification for the selection of surface treatment binders (Research Report 1710-1). The SPG specification is performance-based and utilizes binder properties directly related to surface treatment performance and associated distress. The specification takes into account environmental conditions, aging effects of the binder, visco-elastic behavior, and reliability.

The objective of this second phase of the project was to investigate and establish the validity and applicability of the proposed SPG specification, make modifications where necessary, and, finally, recommend the SPG specification for practical implementation. The research methodology involved highway section identification, laboratory testing including SPG grading, performance monitoring, and comparison of the SPG binder grades to actual field performance. Factors included in the experimental design were binder type and suppliers, environment, aggregates, and traffic. Analyses of the results showed that there is generally a good correlation between the proposed SPG specification and actual field performance. Overall, the results are indicative that the SPG specification is functional and if properly applied, the specification promises to be a relatively cost-effective method for selecting binders to ensure adequate surface treatment performance. However, further validation is recommended, possibly with controlled test sections to fully investigate the effects of design, construction, and quality control processes and address some of the deficiencies of the specification.

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CHAPTER 1. INTRODUCTION

Many government agencies use surface treatments for their maintenance and rehabilitation programs to improve the quality and extend the service life of pavements (*1,2*). These treatments are versatile in their application, ranging from a riding surface course when constructed on top of a base to a maintenance treatment, rehabilitation job, or temporary surface prior to a major reconstruction project. When properly designed and constructed, surface treatments are practical, efficient, and economical solutions that improve the serviceability and ride quality of the pavement and have a life span of up to 7 years (*3,4*). As well as providing a smooth riding surface, surface treatments improve the frictional characteristics of the pavement surface and also reduce water and air infiltration into the pavement (*3*).

The term surface treatment can be employed as a general designation for a treatment utilized to restore the surface quality and useful life of a pavement or provide a surfacing course when constructed directly on a base course. Many treatments, including seal coats, fog seals, sand seals, slurry seals, and microsurfacing, fall under this general classification. The Texas Department of Transportation (TxDOT) defines a surface treatment more narrowly as a single, double, or triple application of asphaltic material covered with aggregate and constructed on an existing pavement or on a prepared base course (*5*). Researchers used the TxDOT definition in this project, which focused on developing and initially validating a performance-graded specification for the binders used in this application. The term binder as used by the researchers in this project refers to asphalt cements and/or emulsions, unmodified or modified.

Adequate in-service performance and cost effectiveness of these surface treatments are partly dependent on appropriate specification and selection of materials for specific environmental and loading conditions. Otherwise, inappropriate specifications and faulty material selection can lead to premature failure or inadequate performance, resulting in a shorter life span for the surface treatment. This is undesirable and costly in terms of subsequent work that may be required. Proper material selection is the first step toward adequate performance, but faulty design, poor construction, and lack of quality control processes are also often the cause of surface treatment failures.

Presently, the conventional method for selecting materials for surface treatments is based on traditional specifications and experience. Most binders do, however, meet traditional specifications, but there are some inadequacies associated with these methods, and experience does not always produce desired results.

Traditional specifications for surface treatment binders are deficient in characterizing material properties directly related to performance. The specifications do not fully take into account the entire temperature spectrum (during production, construction, and in-service) to which the binder is exposed, aging effects of the binder with time, visco-elastic behavior, and reliability. Traditional specifications are essentially consistency specifications based on penetration at 25 °C (ASTM D 946) and viscosity at 60 °C (ASTM D 3381) (*6*). These deficiencies often result in premature failure or inadequate performance of the surface treatment. There is, therefore, a need for new specifications that characterize material properties directly related to performance.

The easiest, quickest, and probably the cheapest way to select materials for any design is experience based on past performance. However, such approaches often fail to account for varying or special conditions, which may result in inadequate performance of the material. Selecting materials based on experience is ideal only if conditions are similar and all other influencing factors remain equal, which in reality is rarely the case.

THE SURFACE PERFORMANCE-GRADED (SPG) SPECIFICATION

Whereas a performance-based binder specification (Superior Performing Asphalt Pavement [Superpave] or performance-graded [PG]) does exist for hot-mix asphalt concrete (HMAC) binders, none exists for surface treatment binders (*7*). The Superpave or PG specification cannot be applied to surface treatments because of the differences in construction methods, structural functions and response behavior, distress types, and environmental exposure. Therefore, in 2000 TxDOT initiated a research project to develop a performance-based specification system for surface treatment binders to address some of the deficiencies of the traditional specifications and the inadequacies associated with material selection based on experience. Researchers developed a new surface performance-graded (SPG) specification, which is shown Table 1 (*1,2*).

Table 1 is the initially proposed SPG specification developed during the first phase of the project. As discussed in subsequent chapters, this was revised in this validation project and the final proposed SPG specification is attached in Appendix A.

Table 1. Initial Proposed SPG Specification.

Performance Grade	SPG 58					SPG 61				
	-13	-16	-19	-22	-25	-13	-16	-19	-22	-25
Average 7-day Maximum Surface Pavement Design Temperature, °C	<58					<61				
Minimum Surface Pavement Design Temperature, °C	>-13	>-16	>-19	>-22	>-25	>-13	>-16	>-19	>-22	>-25
Original Binder										
Viscosity ASTM D 4402 (6) Maximum: 0.15 Pa·s*; Minimum: 0.10 Pa·s Test Temperature, °C	≤180					≤180				
Dynamic Shear, AASHTO** TP5 $\frac{G^*}{Sin\,\delta}$, Minimum: 0.750 kPa Test Temperature @10 rad/s, °C	58					61				
Pressure Aging Vessel (PAV) Residue (AASHTO PP1)										
PAV Aging Temperature, °C	90					100				
Creep Stiffness, AASHTO TP1 S, Maximum: 500 MPa m-value, Minimum: 0.240 Test Temperature @ 8 s, °C	-13	-16	-19	-22	-25	-13	-16	-19	-22	-25

*Pa·s = Pascal-seconds, **AASHTO = American Association of State Highway and Transportation Officials

Table 1 presents only two SPG binder grades as an example, but the grades are unlimited and can be extended in both directions of the temperature spectrum using 3 ^{o}C increments. An example of the SPG binder grade selection process is attached in Appendix B.

Researchers developed the initial SPG specification system (Table 1) through a series of laboratory tests on different TxDOT binders conducted by Barcena et al. (*1,2*) and their corresponding general field performance ranking and associated environmental conditions. It was designed to take into account material properties, distresses, and environmental conditions directly related to the performance of surface treatment binders during production, construction, and in-service. The term distress as used by the researchers in this project refers to surface treatment defects such as aggregate loss, bleeding, etc. and performance refers to the extent of manifestation and degree of severity of these defects with time.

Additionally, the SPG system allows for the inclusion of a reliability factor (in terms of environmental conditions) in the binder grade selection process, thereby making the design more rational and realistic (*1,2*).

The SPG specification was adopted from the Strategic Highway Research Program (SHRP) PG specification for HMAC binders. However, some modifications were utilized to account for the behavior of surface treatments, in-service performance, and associated distresses that are different from those of conventional HMAC (*1*,*2*,*7*,*8*).

The specification assumes proper design and construction practices and considers only binder properties during and after construction, with constructability properties of emulsions required in an additional specification. It is primarily based on temperature grading criteria to preclude aggregate loss and bleeding, which are the predominant surface treatment distresses resulting from inappropriate material selection.

If properly applied, the new SPG binder specification promises to be a relatively cost-effective method for selecting binders to ensure adequate surface treatment performance.

OBJECTIVE

The research project discussed in this report was a continuation of the TxDOT project that resulted in the SPG binder specification (*1,2*). The primary objectives of the project were to:

1) investigate and establish the validity and applicability of the proposed SPG specification, and where necessary make modifications, and
2) recommend the specification for practical implementation.

The researchers' approach was to test and grade various binders used in the field based on the proposed SPG specification criteria and compare the SPG binder grades to actual field performance. All SPG test measurements are performance-based and utilize standard SHRP PG testing equipment, with some modified procedures, consistent with surface treatment design, construction, behavior, in-service performance, and associated distress (*1,2*).

SCOPE OF THE PROJECT

Although design, construction, and quality control processes significantly impact performance of surface treatments, these aspects were not the researchers' primary focus in this project (*9,10,11*). The SPG specification proposed in this project requires proper binder selection, which may be a necessary condition for adequate performance.

This initial validation of the SPG specification assumed that design, construction, and quality control processes were sufficient for adequate performance. This assumption can only be confirmed in subsequent work beyond the scope of this project through the use of controlled test sections, carefully constructed and monitored. In the absence of this further validation, design, construction, and quality control processes are discussed only for cases in this project where the SPG specification results did not correlate with observed field performance and/or where there was failure in the SPG specification and/or inadequate performance in the field.

This report presents the methodology recommended by Barcena et al. (*1,2*), the experimental design, results, and analysis, followed by a discussion, conclusions, and recommendations.

CHAPTER 2. VALIDATION RESEARCH METHODOLOGY

The research methodology for the initial validation of the proposed SPG specification involved four major tasks. These included highway section identification including project data collection, laboratory testing including field binder sampling and SPG grading, and field performance monitoring. Each of these major tasks shown in Figure 1 is discussed in this chapter. The fourth and final task discussed in subsequent chapters included data analysis and a comparison of the SPG binder grading with actual field performance.

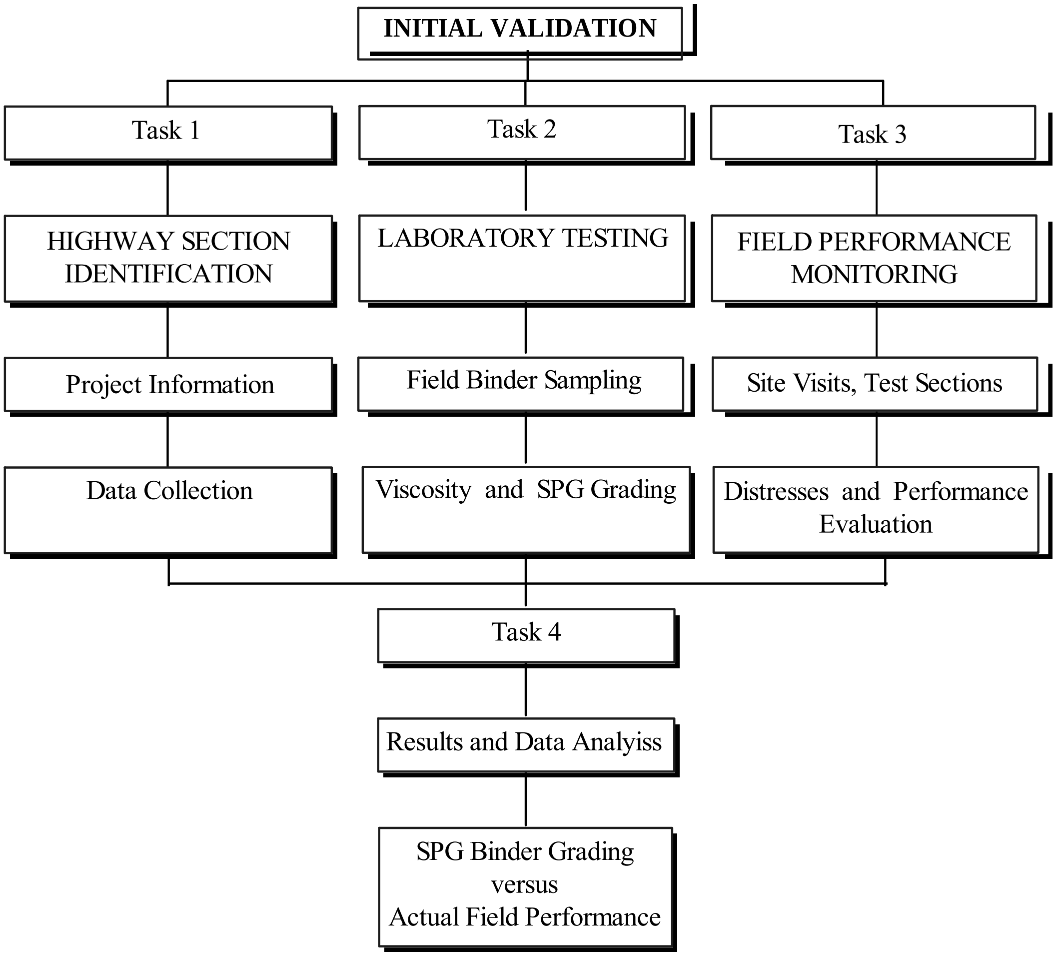


Figure 1. Research Methodology.

HIGHWAY SECTION IDENTIFICATION

The researchers' first task in implementing the objective of the project was to identify and select highway sections or projects in a number of TxDOT districts that were utilizing surface treatments for their highway maintenance and/or rehabilitation programs. A total of 45 highway sections were identified from the 2001 (fall) and 2002 (spring and summer) TxDOT district seal coat programs. These are listed in Appendix C and were arbitrarily designated as HS1 through HS45 for easy reference. Details provided for each highway section include the highway name, length, location, materials used, traffic data, and construction date. All the highway sections were single surface treatments, and a total of seven different types of binders were used. These binders are discussed in more detail in Chapter 3.

For each highway section, researchers also collected the following data: binder type, binder supplier, aggregate type and gradation, aggregate supplier, binder and aggregate application rates, pavement structure, traffic level, compaction details, condition of existing pavement, weather, and contact information. Additionally, the researchers also collected design application rates for typical materials and the recommended pavement surface temperatures at construction for some TxDOT districts. These details are summarized in Appendix C. An example of the project information collected is attached as Appendices D and E. These data were used in analyzing the performance of the individual highway sections and their respective binders and investigating whether design and/or construction played a role in performance.

As shown in Figure 2, the selected highway sections span 13 of the 25 TxDOT districts and cover a wide range of common materials and environmental and traffic conditions to ensure that the SPG specification is valid for Texas conditions. The length of the highway sections ranged between 1.1 miles and 30 miles.

Figure 2. District Location of the Selected Highway Sections.

(drawing not to scale or exact)

LABORATORY TESTING

Samples of binders used during construction of surface treatments for the selected highway sections were collected for laboratory testing and SPG grading. The sampling point was either in the binder production plant prior to being delivered to the site or onsite before and/or while being applied to the pavement surface. Most of the binders were sampled onsite. Researchers then conducted tests on the sampled binders in accordance with the proposed SPG test criteria, and graded the binders accordingly.

For any given binder, the design-related factors that affect surface treatment performance include binder grade and properties and binder viscosity during construction (*12*). The SPG binder tests directly relate to these factors. These tests are discussed in the following subsections.

Rotational Brookfield Viscosity Testing

Binder consistency in terms of viscosity during application is an important factor in surface treatment performance and is largely controlled by the spraying temperature (*10*). Optimum binder temperature is essential to ensure optimum binder viscosity, uniformity, and adequate aggregate embedment at the time of construction to prevent run-off and minimize aggregate loss. Spraying the binder at temperatures lower or higher than optimum could be a potential source of aggregate loss, due to either high or low viscosity, respectively (*1,2*). Binders that are sprayed at colder temperatures than optimum tend to be viscous and do not allow proper embedment of the aggregate, resulting in potential aggregate loss. If the binder is sprayed too hot, it is prone to flow, causing the same effect. Extremely high temperatures can also increase aging and/or alter the binder properties to the detriment of performance (*1,2*).

Viscosity testing was conducted in accordance with the standard SHRP rotational Brookfield viscosity test procedure (*7,8*). An approximately 8 g sample of binder is required for the test. The measurable parameter is the temperature at which the binder viscosity falls within a 0.10 Pa·s to 0.15 Pa·s range based on recommended values from 0.05 Pa·s to 0.20 Pa·s (*13,14,15,16*). In the case of asphalts, this temperature is equivalent to the spraying temperature at which the binder will have optimum viscosity to wet and hold the aggregate in place during construction and under traffic without excessive aging, alteration of the binder chemical properties, or degradation of the modifiers (*1,2*).

Whereas spraying viscosity can be specified for proper binder selection, these desirable properties are also dependent on pavement temperature and weather conditions at the time of construction. Kari et al. (*10*) recommended minimum pavement temperatures of 12 ^{o}C for emulsions and 43 ^{o}C for asphalt cements, and a maximum of 66 ^{o}C. Wegman (*9*) specifies a minimum temperature of 21 ^{o}C for surface treatment binders. TxDOT generally recommends minimum pavement surface temperatures of approximately 16 ^{o}C and 21 ^{o}C for unmodified (including emulsions) and modified binders, respectively (*5*).

High-Temperature Testing and SPG Grading

High-temperature properties are critical in specifying surface treatment binders to preclude aggregate loss and to minimize bleeding at high service temperatures due to low shear resistance and the inability of the binder to hold the aggregate in place under traffic forces. The standard SHRP dynamic shear rheometer (DSR) was used for high-temperature binder testing and SPG grading. An approximately 2 g, 1 in. diameter by 0.04 in. thick, circular specimen of binder sample is required for the test. This test gives the upper temperature limit of the binder grade (e.g., SPG 67-XX). The measurable parameter is the highest temperature at which the $G^{*}/Sin\ \delta$ value is equal to or greater than 0.75 kPa. G^{*} is the complex modulus that represents a measure of the resistance of binder to shear, and the phase angle δ takes into account the visco-elastic behavior of the binder (*1,2,7,8*).

In addition to the modified $G^{*}/Sin\ \delta$ limit (1.00 kPa in case of the SHRP PG system), DSR testing is performed only on the unaged (original) binder to reflect critical conditions for newly constructed surface treatments. The temperature grade increment is ±3 ^{o}C, and this high-temperature limit is representative of the average 7-day maximum pavement surface design temperature (*1,2,7,8*).

Low-Temperature Testing and SPG Grading

Low-temperature properties are also critical in specifying surface treatment binders to preclude aggregate loss at low temperatures when the binder stiffness is high, causing fracture under traffic loading (*1*,*2*). In the modified bending beam rheometer (BBR) test, the binder is characterized in terms of flexural creep stiffness (*S*) and the log stiffness-log time slope (*m-value*) at a loading duration of 8 seconds for binders aged only in the pressure aging vessel (PAV) to represent the critical aging state for low-temperature properties of surface treatments (*1*). An approximately 15.5 g, 5 in. long by 0.5 in. wide by 0.25 in. thick beam specimen of binder sample is required for the BBR test.

The measurable parameter is the lowest temperature at which the *S* value is equal to or less than 500 MPa and the *m-value* is equal to or greater than 0.24 (*1*,*7*). The PAV aging test parameters are approximately 2 MPa pressure, 90-100 ^{o}C temperature, and 20 hours aging time (*7*,*8*).

In summary, the PAV-BBR test results determine the lower temperature limit of the binder grade (e.g., SPG XX-13), and the temperature grade increment is also ±3 ^{o}C (*1*,*2*,*7*,*8*). This low-temperature limit is representative of the 1-day minimum pavement surface design temperature.

Emulsion Residue Recovery Process

An emulsion is a chemical mixture of unmodified or modified asphalt, an emulsifying agent, and water (in a continuous phase). The addition of an emulsifying agent and water to asphalt enables the emulsion to be applied at relatively low spraying temperatures. The modifiers enhance the emulsion viscosity and adhesion properties (*8,17,18,19,20)*.

Because the SPG specification system is performance-based, it primarily characterizes the material properties of the binders after construction, after the water has evaporated from an emulsion (*1*,*2*). To simulate this effect, water must be removed from the emulsion prior to laboratory testing and SPG grading.

Stirred Can Method

Among the various emulsion residue recovery processes considered, the stirred can method was found by the researchers to be most suitable and was subsequently recommended for use throughout the project (*1*). The method involves pouring 1200 g of an emulsion sample into a 3.79 L can and constantly stirring for about 170 minutes at a test temperature of 163 °C. It has a residue yield potential of approximately 66.67 percent. A nitrogen blanket minimizes oxidation during the process (*1,2*).

Although it does not fully simulate field conditions (due to the heating effect), the stirred can method yielded better results in terms of the residue quantity, minimization of asphalt oxidation, maximization of water removal, and optimization of the recovery process time (170 minutes) compared to other methods reviewed (hot oven, rotovap, hot plate, and distillation) (*1,2,21*). In the field, water evaporates freely from the emulsion under natural conditions without direct applied heating.

Additionally, the same simple stirred can apparatus can also be used for short-term aging of asphalts in a test setup called the stirred airflow test (SAFT) (*22*).

Other Emulsion Recovery Methods

Researchers reviewed other emulsion recovery methods through the literature after development of the stirred can method. These included the rolling thin film oven test (RTFOT), forced air-drying, and distillation and evaporation methods.

The RTFOT Method. The RTFOT method, described in a study by Takamura (*23*), offers the shortest residue recovery time of approximately 75 minutes and possibly very minimal oxidation, due to the lower temperature (85 ^{o}C) used in the process. The procedure involves rotating thin films of emulsions in polytetrafluoroetheylene (PTFE) bottles at 85 ^{o}C with a flow of heated nitrogen gas jetted over the binder film to evaporate the water (*23*). Residue recovery mass potential is about 63 percent per 200 g of emulsion sample.

However, the method lacks merit because of the fact that there is incomplete water removal with some CRS-2P emulsions. This renders this method inapplicable because production of consistent residue is required and one of the binders considered in the project was a CRS-2P emulsion.

Forced Air-Drying Method. A forced air-drying procedure closely simulates field conditions, with a residue recovery mass potential of approximately 65 percent per 50 to 60 g of emulsion sample. In this procedure, water evaporates freely with the aid of air flow over the emulsion surface at ambient temperature (approximately 22 °C). It is a slow process (300 to 360 minutes) to complete, and often the residue requires approximately one day to prepare (*23*). Because of the relatively low drying temperature, the probability of altering the binder chemical properties is minimal. The forced air-drying procedure appears to be the best emulsion recovery method in terms of simulating field conditions, but this method was not considered during development of the stirred can method.

Vacuum Distillation Method. The vacuum distillation method, though conducted at a relatively lower temperature (115 °C), produces undesirable artificial macroscopic polymer structures that result from a freezing effect (*23*). This results in the residue viscosity inconsistency and thus makes the method less favorable.

Takamura (*23*) also reported that the major problem associated with distillation and evaporation methods is the possibility of overheating, which can lead to excessive oxidation and/or alteration of the chemical properties of the binder including degradation of the modifiers. Often, these methods involve heating to temperatures over 160 °C.

FIELD PERFORMANCE MONITORING

To relate laboratory testing and the SPG specification to actual field performance, researchers initiated a site-visit survey program to monitor the performance of highway sections that utilized the sampled, SPG tested, and graded binders. The intent was to assess performance of the binders in terms of the SPG specification and distress criteria. By comparing laboratory test results (SPG grades) and actual field performance of the binders, validation of the SPG specification was possible. The underlying principle (rationale) was that if the SPG specification indicated that a binder would not perform adequately in a given environment based on the pavement surface temperature criteria, then inadequate performance would be recorded in the monitoring program. Results should also prove the corollary: if the SPG specification predicts adequate performance, then the binder should perform adequately in the field. If the specification prediction and actual performance did not agree, then the effect of other influencing factors was thoroughly investigated and/or the SPG specification was reviewed and modified accordingly.

In the following subsections, the performance monitoring schedule, visual surveys, test sections, distresses, and the surface condition index (SCI) criteria for performance evaluation are described. A brief discussion of digital images of highway sections and distresses that were recorded during the site visits is also presented.

Site Visits and Performance Monitoring Schedule

Within the scope of the project, researchers conducted 1-year of performance monitoring with three visual inspections per highway section to ensure that each highway section was at least subjected to a complete seasonal cycle to account for the traffic changes and aging. The site visit schedule entailed an initial inspection just after construction and consecutively after the summer and winter seasons. Failure (aggregate loss, bleeding, etc.) of the majority of surface treatments often occurs either in the first summer, due to high temperatures, and/or winter, due to low temperatures, that impact the binder properties. Generally, it is also hypothesized that surface treatments, with inappropriate materials or those that were poorly designed and constructed often fail in the first year of their service life (*12*).

Visual Surveys and Field Measurements

For this initial validation project, the visual survey technique was used for monitoring the performance of the surface treatments on the selected highway sections. An example of a field performance monitoring survey sheet is attached as Appendix F. A visual survey is relatively easy and distinctively evaluates distresses directly related to binder properties to meet the objectives of this project. With visual examination, three performance-rating parameters (aggregate loss, bleeding, and overall) are provided and the distress failure mode can easily be defined (*24*). In this validation project, these parameters were directly tied to binder properties including the SPG grades (*1,2*). Additionally, visual examination offers the advantage of being able to survey and evaluate an entire highway section (*24*). Furthermore, neither detailed failure analysis nor comparative performance ranking of the highway sections was required in the project, and thus researchers considered a visual survey to be adequate.

During these visual surveys of three inspections per test section on each highway section, field measurements of distresses were recorded in square feet (ft^2) of affected surface area, consistent with the SHRP distress identification manual (*25,26*). An example of these field measurements is shown in Appendix G.

As discussed subsequently, the visual surveys and field measurements were also supplemented by digital recording of images of highway sections, while actual performance evaluation and rating were analyzed using the SCI criteria.

Test Sections

In this project, researchers defined a highway section (HS) as a section or an entire length of a highway or roadway that was surfaced, resurfaced, or rehabilitated using a surface treatment that incorporated a binder that was sampled and SPG graded. As stated previously, the length of these HSs ranged between 1.1 miles and 30 miles. A test section (TS) was defined as a representative subsection of a HS with an area of approximately 5000 to 7000 ft^2 for which performance monitoring was conducted (*3,27*). Some of the TS characteristics are listed as follows:

- Each TS was 500 ft long and 10 to 14 ft wide (Appendices F and G) (*24*). The width was simply taken as the equivalent highway lane width.
- Two to four TSs were utilized depending on the length of a HS. Overall performance of each HS was the average summation of the performance of the individual TSs.
- Multiple TSs were used to avoid the possibilities of overrating or underrating performance due to the absence or presence of localized distresses or geometric features such as turns or changes in surface elevation.

- For the 45 HSs, there were approximately 150 TSs in total. Inspecting the entire HS for the monitoring program was beyond the time and budget constraints of the project, and hence representative TSs were used.
- Researchers collected data from outside lanes with slower and heavier traffic on HSs with more than one lane per direction. This practice also increased safety.
- TSs were randomly selected from both directions to take into account any variations in the traffic pattern.
- Intersections, junctions at access roads, grades, and curves were avoided to minimize the effects of extremely slow and turning traffic, which could exaggerate distress. This decision was also made for safety reasons and ease of performance evaluation.
- TSs were marked using existing reference points or objects such as road mile marker signs. Where unavailable, the TS reference points were physically marked using spray paint.

Distresses

The distresses monitored on each TS included aggregate loss (raveling), bleeding, and cracking. Aggregate embedment was also measured. These distresses are discussed in the subsequent subsections.

Aggregate Loss (Raveling)

Aggregate loss or raveling is the principal distress associated with surface treatments and controlled by the SPG specification system. Aggregate loss is the loss of loose materials (usually aggregate) that “ravel” from the surface or edges of the pavement. This aggregate loss results in exposed binder or depressions, which may fill with loose aggregate and/or with water (during and/or after rainfall). This situation may pose safety problems. Aggregate loss reduces the frictional characteristics of the pavement surface, causing braking and skid resistance problems. Loose aggregates are also a potential source of windshield damage, especially where coarse aggregates are used (*3,28*).

Causes of aggregate loss include the binder being unable to hold the aggregate in place (related to the binder viscosity), dusty aggregates, insufficient compaction and embedment (construction problems), an aged binder, and stripping (moisture damage) (*8,9,10,28,29,30*). However, this project primarily focused on causes directly related to binder properties and behavior and thus binder selection to ensure adequate performance at all service temperatures.

Researchers measured and recorded aggregate loss in ft^2 of affected surface area at each severity level. Low, moderate, and high severity levels were used and were defined consistent with the SHRP distress identification manual as shown in Table 2 (*24,25*).

Table 2. Severity Levels for Aggregate Loss.

#	Level	Description
1	Low	The aggregate has begun to ravel off but has not significantly progressed. Evidence of loss of some fine aggregate.
2	Moderate	Surface texture becoming rough and pitted; loose particles generally exist; loss of fine and some coarse aggregates.
3	High	Surface texture very rough and pitted; loss of coarse aggregates.

Bleeding

Bleeding occurs as a shiny, black, or glasslike reflective surface caused by liquid binder migrating to the pavement surface, often in the wheelpaths (*24,25*). It can also be defined as a film of excess bituminous binder occurring on the pavement surface. The result can be a dangerous, slippery pavement due to decreased frictional characteristics between the tire and pavement surface. Often, bleeding occurs at high pavement temperatures due to high binder content (associated with design and construction), low binder viscosity, use of very small aggregates and excessive embedment, inadequate and/or loss of aggregates, excessive compaction during construction, and high traffic (*8,12,13,16,29,30*).

Like aggregate loss, bleeding was measured and recorded in ft^2 of affected surface area at each of three severity levels (low, moderate, and high), consistent with the SHRP distress identification manual. The severity levels are described in Table 3 (*24,25*).

Table 3. Severity Levels for Bleeding.

#	Level	Description
1	Low	An area of pavement surface discolored (black) relative to the remainder of the pavement.
2	Moderate	Distinctive black appearance and loss of surface texture due to free excess binder.
3	High	Wet-black shiny appearance on the pavement surface due to excess binder; excess binder may obscure aggregates; tire marks may be evident in warm weather.

Cracking – Transverse and Longitudinal

Transverse (perpendicular to the pavement centerline) and longitudinal (parallel to the pavement centerline) cracks were considered as structural distresses often related to the underlying pavement structures (e.g., HMAC, and not the surface treatment itself) (*8,12,29,30,31*). Therefore, they were not of primary focus in this project. Where observed however during performance monitoring, the cracks were noted and reported in the analysis.

Aggregate Embedment

Researchers measured aggregate embedment in terms of the percentage of the vertical dimension (embedded portion) of the aggregate covered with binder. This is a function of the mat thickness (as described in the Kearby design curve) and traffic intensity (*32,33*). The recommended aggregate embedment for adequate performance for high and low traffic volume highways just after construction are 20 to 30 percent and 30 to 40 percent, respectively (*33*). However, some literature recommends initial embedment values as high as 50 percent (*9*). About 70 ± 10 percent aggregate embedment is considered reasonable after 2 years of service (*33*).

Greater embedment is indicative of inadequate performance likely to aggravate bleeding and/or contribute to the pavement surface's poor frictional properties. Possible causes of undesirable aggregate embedment include low binder viscosity, excessive binder, small aggregate size, traffic (high volume, axle loads, and slow speed), or excessive compaction during construction. By contrast, insufficient aggregate embedment due to high binder viscosity and/or inadequate compaction can lead to traffic whip-off and aggregate loss (*9,10, 29,30*).

Performance Evaluation and Rating Criteria

The SCI criterion was used for performance evaluation and rating of the HSs (1,2,3,27). The actual rating was based on calculated SCI scores, which ranged from 0.00 percent (very poor performance) to 100 percent (perfect performance). For each respective distress, researchers determined the SCI score as an equal weighted function of the distress area coverage (DAC) and the degree of severity of distress (DSD), expressed as a percentage. This is illustrated in Equation 1.

$$SCI_{Distress} = 0.5\left(P_{DAC} + P_{DSD}\right) \text{..(Equation 1)}$$

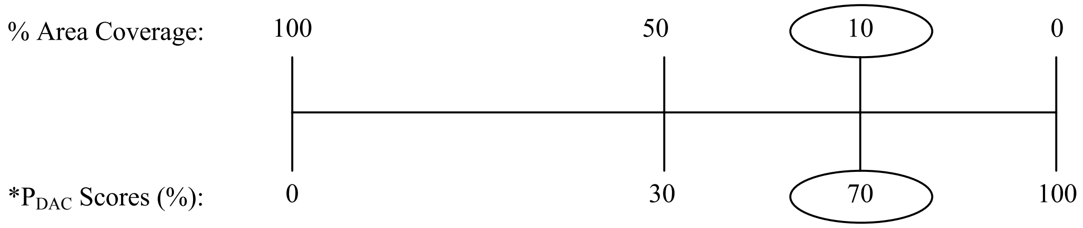
where:

$SCI_{Distress}$ = SCI score as a percentage for a given distress

P_{DAC} = distress area coverage as a percentage

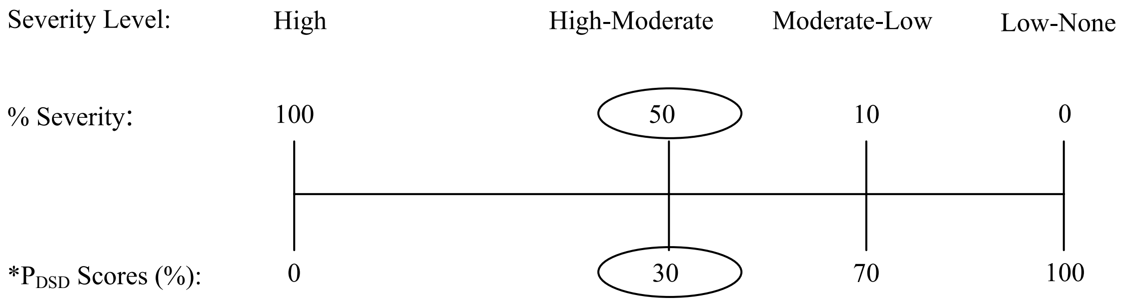
P_{DSD} = degree of severity of a distress in percentage

The SCI scores for P_{DAC} and P_{DSD} were determined as shown in Figures 3 and 4.



*Percent Distress Area Coverage

Figure 3. SCI Distress Evaluation and Scores - Distress Area Coverage (DAC).



*Percent Degree of Severity of Distress

Figure 4. SCI Distress Evaluation and Scores – Degree of Severity of Distress (DSD).

Overall Highway SCI Scores

For each HS, each distress was evaluated, analyzed, and reported separately, but may still be combined (where necessary) to get the overall highway SCI score and performance rating. This is illustrated in Equations 2 and 3.

$$SCI_{Overall} = [\alpha_{AL} \times SCI_{AL}] + [\alpha_{BL} \times SCI_{BL}] + ... + [\alpha_{Distress} \times SCI_{Distress}] \text{.............(Equation 2)}$$

and:

$$\alpha_{AL} + \alpha_{BL} + ... + \alpha_{Distress} = 1.00 \text{ ....(Equation 3)}$$

where:

$SCI_{Overall}$ = overall highway SCI score as a percentage
SCI_{AL} = SCI score for aggregate loss as a percentage
SCI_{BL} = SCI score for bleeding as a percentage
$SCI_{Distress}$ = SCI score for other distresses as a percentage
α_{AL} = distress weighting factor for aggregate loss (~0.80)
α_{BL} = distress weighting factor for bleeding (~0.20)
$\alpha_{Distress}$ = distress weighting factors for other distresses

Distress Weighting Factors and Threshold Values

The overall highway SCI score is the summation of the individual weighted distress SCI scores and should add up to 100 percent if performance is adequate with no distress (*1*,*2*). The weighted distress scores and SCI threshold values are summarized in Tables 4 and 5, respectively. The distress weighting factors (α_i) of 0.80 for aggregate loss and 0.20 for bleeding were arbitrarily assigned based on the degree of significance of the distress in relation to surface treatment performance, the binder properties, and the SPG specification. Since only aggregate loss and bleeding were evaluated, weighting factors for other distresses such as cracking were zero (i.e., $\alpha_{Cr} \cong \alpha_{Distress} = 0.00$).

Researchers rated the HS performance as good, fair, or poor using the threshold values shown in Table 5 (*1*,*2*). These values were also arbitrarily selected and may still be subject to review. Based on this performance rating scale, researchers selected an SCI score of 70 percent as the threshold value to define *Pass* (adequate performance) and *Fail* (inadequate performance) for validating the SPG specification. An SCI score equal to or greater than 70 percent constituted a *Pass*, and scores less than 70 percent indicated a *Fail*. While some literature recommend and/or use a SCI score of 75 percent as a threshold value, a 5 percent tolerance (lowering the performance threshold to 70 percent) was used in this validation study to account for any possible variations, inaccuracies, and errors in visual distress measurement and SCI calculations (*1*,*2*,*3*). An example of a field survey, SCI calculations, and performance rating criteria is attached as Appendices G and H.

Table 4. Weighted SCI Scores by Distress Type.

#	Distress	Weighting Factor (α_i)	Weighted Distress SCI Score (%) for Overall Highway Performance
1	Aggregate Loss (SCI_{AL})	0.80	$0.80 \times (SCI_{AL})$
2	Bleeding (SCI_{BL})	0.20	$0.20 \times (SCI_{BL})$
3	Cracking (SCI_{Cr})	0.00	$0.00 \times (SCI_{Cr})$
4	Other Distresses ($SCI_{Distress}$)	0.00	$0.00 \times (SCI_{Distress})$
Total (assuming perfect performance)		1.00	100.00

Table 5. SCI Threshold Values and Overall Performance Rating Criteria.

SCI Threshold Value (*1,2,3,24*)	Performance Rating	SPG Validation
$\text{SCI} \geq 70\%$	Good	$\text{SCI} \geq 70\%$ = *Pass* (Adequate Performance)
$55\% \leq \text{SCI} < 70\%$	Fair	$\text{SCI} < 70\%$ = *Fail* (Inadequate Performance)
$\text{SCI} < 55\%$	Poor	

For all HSs, the initial SCI scores at the time of construction were taken as 100 percent, and performance was rated as good (*Pass*) with no distress. This was based on the assumption that design and construction were adequate.

Digital Images of Highway Sections and Distresses

During performance monitoring, surface treatment condition was recorded electronically using a digital camera. Images of the pavement surface at the same location were taken consecutively during each site visit to visually illustrate how the pavement surface condition (performance) changed with time. These are discussed subsequently, and images of selected HSs and distresses are included in Appendix K.

At any given location on a TS, researchers took the following four images: the entire surface cross-section of the highway, the right wheelpath, between the wheelpaths, and the left wheelpath. These images showed a representative pictorial view of a HS in terms of the pavement surface condition as a supplement to the visual surveys and field measurements.

CHAPTER 3. VALIDATION EXPERIMENTAL DESIGN

An analytical factorial design to estimate main effects related to surface treatment performance served as the basis for the initial experimental design recommended during development of the SPG specification (*1,2,34*). The experimental design was limited to two levels of each of the influencing factors and required specific factor-level combinations. Table 6 shows an example of the factorial experimental design for AC15-5TR. The design was made in such a way that it required field information to meet these specific factor-level combinations. There was no flexibility to accommodate actual available HSs. This type of design became impractical to implement, and thus researchers developed a modified experimental design based on available field project information and the selected HSs.

Table 6. Example of a Factorial Experimental Design for AC15-5TR.

Binder Supplier (BS)	Environment (E)	Traffic (T)	Aggregate (A)	Modifier (M-modified, U-unmodified)
BS 1	E 2	T 2	A 1	M
BS 1	E 1	T 1	A 2	M
BS 1	E 1	T 2	A 1	U
BS 1	E 2	T 1	A 2	U
BS 2	E 2	T 2	A 1	M
BS 2	E 1	T 2	A 1	U
BS 2	E 1	T 1	A 2	M
BS 2	E 2	T 2	A 2	U

In formulating the modified experimental design, researchers ensured that it was consistent with the project objective and included information available for the selected HSs. Figure 5 shows the modified experimental design represented in a flow chart. This design was formulated from the surface treatment project information gathered and the respective influencing factors. The influencing factors were defined as those factors that were considered to affect the in-service performance of surface treatments. The significance of the influencing factors relate to the control of performance through the SPG specification.

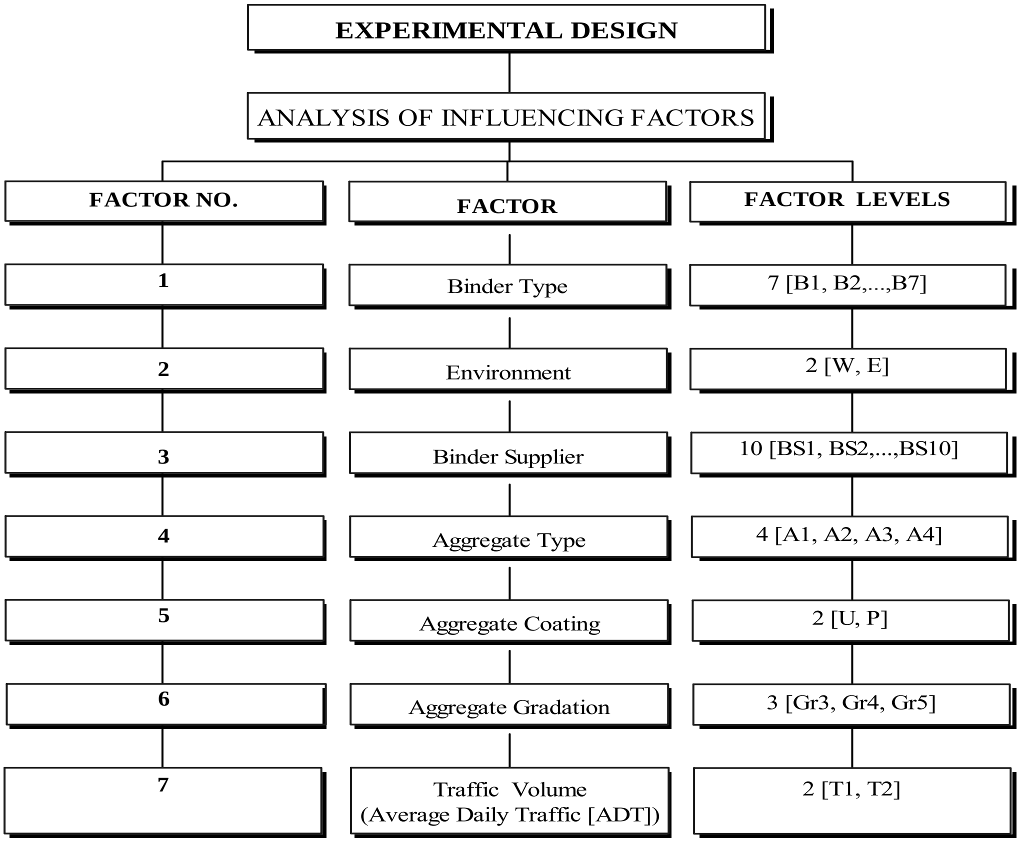


Figure 5. Flow Chart for the Modified Factorial Experimental Design.

Researchers considered binder type as the most significant factor influencing surface treatment performance in relation to the SPG specification, followed by environment, and subsequently by binder supplier, aggregate (type, precoating, and gradation), and traffic. For each factor, the following number and names of levels are shown in Figure 5: seven binder types (B1 to B7), two environmental conditions (West and East), ten binder suppliers (BS1 to BS10), four aggregate types (A1 to A4), two aggregate coating designations (uncoated or precoated), three aggregate gradations (Gr3, Gr4, and Gr5), and two traffic volume categories (T1 and T2). Each factor and its associated levels are discussed subsequently.

BINDER TYPES

Binder type was the primary factor both in the development and initial validation process of the SPG specification. The intent of the experimental design was therefore to sample the most common binder types used in the state of Texas. From the 2001 and 2002 TxDOT district surface treatment programs, seven different types of binders (designated B1 to B7) were identified, and all were modified. These binders are summarized in Table 7. The binders were sampled, tested, and graded according to the SPG specification.

Table 7. Binders.

#	Designation	Binder	Brief Description	# of HSs
1	B1	AC15-5TR	Asphalt cement with 1500 poises viscosity @ 60 ^{o}C, modified with 5% tire rubber.	18 (40%)
2	B2	AC-15P	Asphalt cement with 1500 poises viscosity @ 60 ^{o}C, modified with a polymer.	5 (11%)
3	B3	AC5-2% Latex	Asphalt cement with 500 poises viscosity @ 60 ^{o}C, modified with 2% latex	7 (15.6%)
4	B4	AC10-2% Latex	Asphalt cement with 1000 poises viscosity @ 60 ^{o}C, modified with 2% latex	3 (6.7%)
5	B5	CRS-2P	Cationic, rapid setting, high viscosity emulsion modified with a polymer	3 (6.7%)
6	B6	CRS-2H	Cationic, rapid setting, high viscosity emulsion with a hard base asphalt	4 (9%)
7	B7	PG76-16	Performance graded asphalt cement with a temperature susceptibility of 76 ^{o}C to -16 ^{o}C.	5 (11%)
Total number of HSs				45

It was necessary for the researchers to consider as many binder types as possible to evaluate individual performance relative to the SPG specification and to compare the results. Because of the differences in chemical properties, researchers assumed that an AC15-5TR that graded as a SPG 70-16 could perform differently from a CRS-2P that also graded as a SPG 70-16. For example, though both binders could perform adequately, the performance rating could be different.

The binder spectrum was limited as shown in Table 7 due to the fact that not all binder types utilized in development of the SPG specification were used in the selected HSs and none were unmodified (*1,2*). The most commonly used binder type was AC15-5TR (Table 7), with 40 percent of the HSs utilizing this material.

ENVIRONMENTAL CONDITIONS

Environment was one of the primary factors investigated in the initial validation of the SPG specification. This specification was developed to ensure adequate performance of surface treatment binders in a specific environment. In this project, the Texas environment was broadly categorized into two climatic regions, West (W) and East (E), using interstate highway I-35 as the boundary. The West is considerably drier with temperature ranges much more extreme than the East, which is more humid. In both climatic regions, however, the northern part is generally associated with freeze and thaw cycles (*35*).

The SPG specification system accounts for environmental conditions in terms of the high and low pavement surface temperatures (*1,2*). Although environment was broadly categorized as West and East, each TxDOT district was further differentiated by pavement surface temperatures as shown in Figure 6, both at 50 and 98 percent reliability. For the SPG validation analysis, researchers used only temperatures at 98 percent reliability obtained from weather stations closest to the selected HSs (*35,36*). A high reliability level of 98 percent was selected because it is more conservative and was thus considered ideal for a validation study where the design assumption for the binder grade selection was for a worst case scenario. Most practical designs and analyses use 95 percent reliability.

The pavement surface temperatures shown in Figure 6 were obtained from the LTTPBind V2.1 database as a function of latitude, air temperature, and statistical reliability (*34,35*). The temperatures represent average values summed over multiple locations within a TxDOT district, with temperature data collected over a period of more than 20 years.

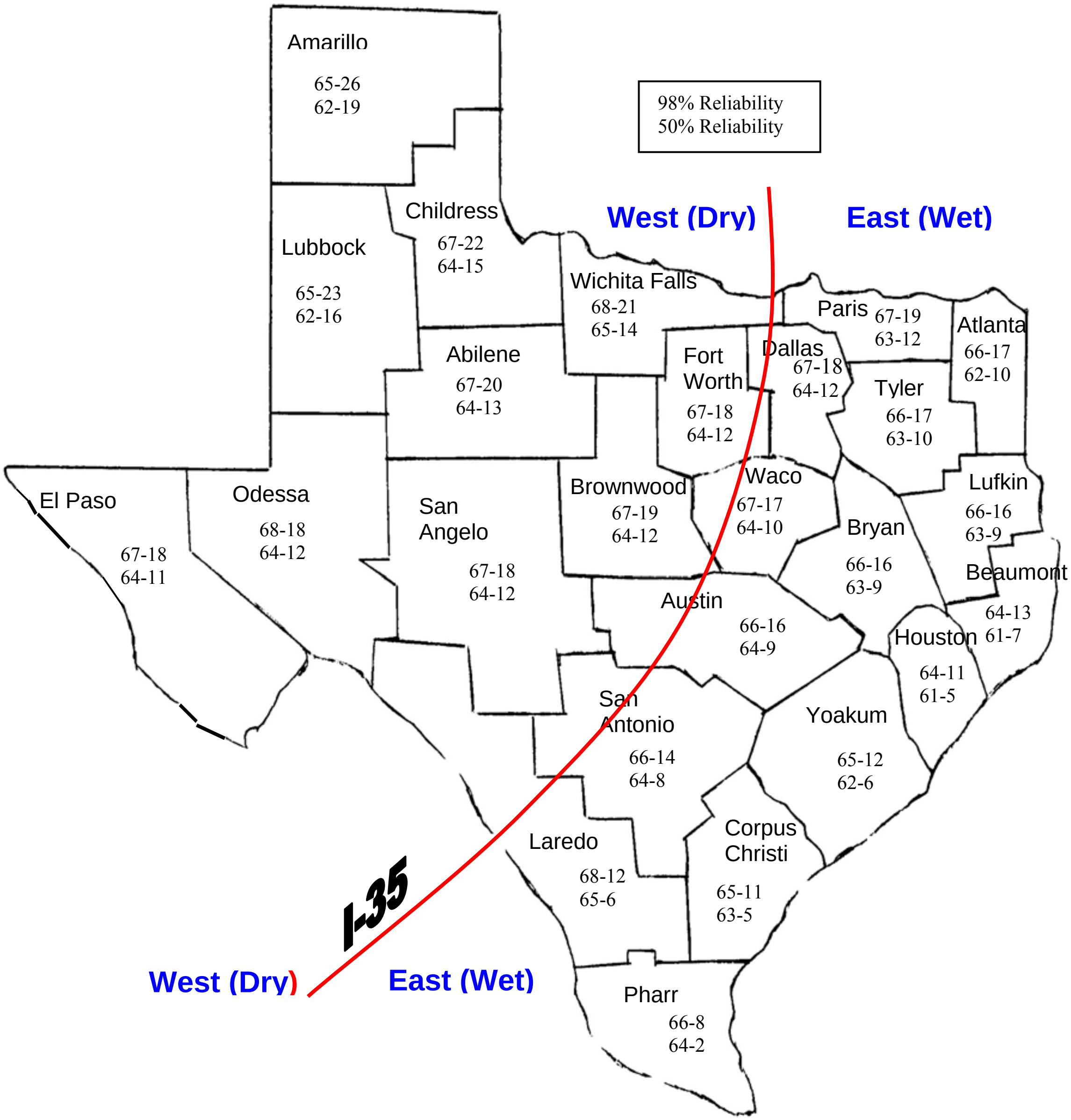


Figure 6. TxDOT District Pavement Surface Temperatures.

(drawing not to scale or exact)

BINDER SUPPLIERS

Ten different suppliers produced the binders sampled from the selected HSs. The binder suppliers were designated as BS1 to BS10. Researchers selected this factor in the experimental design to capture any differences in the modifiers, manufacturing, and quality control processes among the suppliers. Binders from different suppliers may have different properties and/or different SPG grades and therefore could perform differently.

AGGREGATES

Once applied on the pavement surface, the binder and aggregate ultimately behave as a composite material and their individual properties simultaneously affect one another. Therefore, aggregate characteristics such as type, gradation, and precoating have a profound effect on the performance of the binders and surface treatment as a whole (*1,3,4,5,37,38*). The selected HSs used four aggregate types (lightweight, limestone, gravel, and sandstone) with TxDOT gradations 3, 4, and 5 (*5*). Researchers designated these factor levels as shown in Table 8, and these are discussed subsequently. Unlike for the binders, the aggregate supplier effect was considered secondary and insignificant and was therefore not taken into account in the analysis.

Table 8. Aggregate Types and Gradation Grade Designations.

Aggregate			Aggregate Gradation		
Designation	Type	# of HSs	Designation	Gradation	# of HSs
A1	Lightweight	12 (27%)	Gr3	Grade 3	15 (33.3%)
A2	Limestone	23 (51%)	Gr4	Grade 4	29 (64.5%)
A3	Gravel	6 (13%)	Gr5	Grade 5	1 (2.2%)
A4	Sandstone	4 (9%)			

As evident from Table 8, the most commonly used aggregate type was limestone, with 51 percent of the HSs using this aggregate, followed by lightweight with 27 percent of the HSs utilizing this aggregate. Only 9 percent used sandstone.

Aggregate Precoating

Often, the aggregates for surface treatments are precoated with a binder to increase their adhesion properties and minimize moisture absorption and dust production during construction. Because of precoating, aggregate loss due to the presence of dust or other dirty substances is also minimized (*10,12,33,39*). In this project, researchers used the designation '*U*' and '*P*' to denote uncoated and precoated aggregates, respectively. Eighty-four percent of the selected HSs used precoated aggregates. This factor was investigated to evaluate how it affects surface treatment performance and if it had any significant effect on binder selection and subsequently the SPG specification. In the project, the effect of the type of precoating material was not considered.

By contrast, the use of precoated aggregates is generally not recommended if the binder is an emulsion. Precoating inhibits the chemical breakup, absorption, and adhesion of the emulsion to the aggregate (*33,40*).

Aggregate Gradations

Figures 7 and 8 show typical TxDOT gradation specifications for grades Gr3, Gr4, and Gr5 aggregate (*5*).

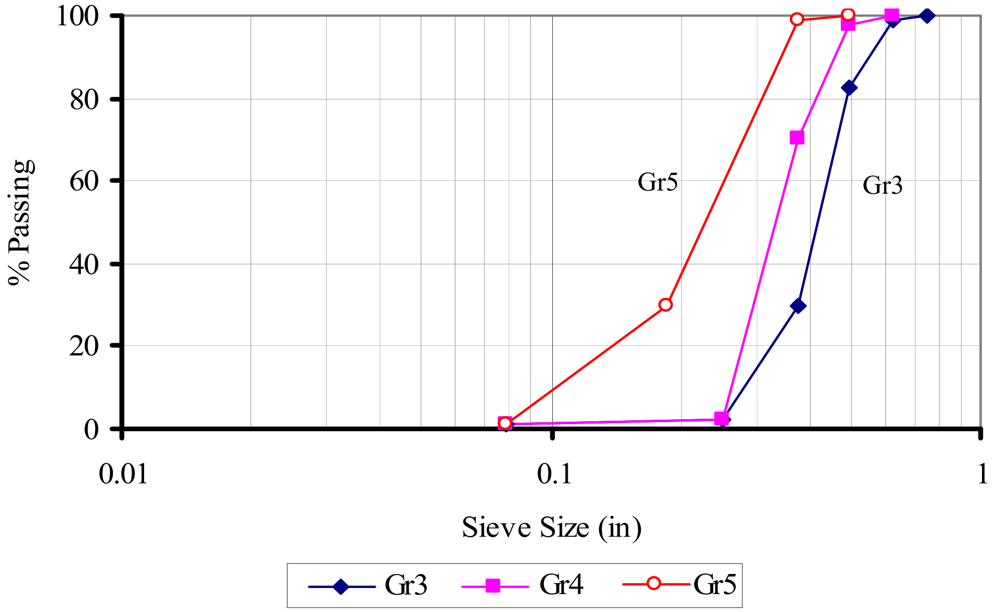


Figure 7. Aggregate Gradations for Lightweight Aggregate.

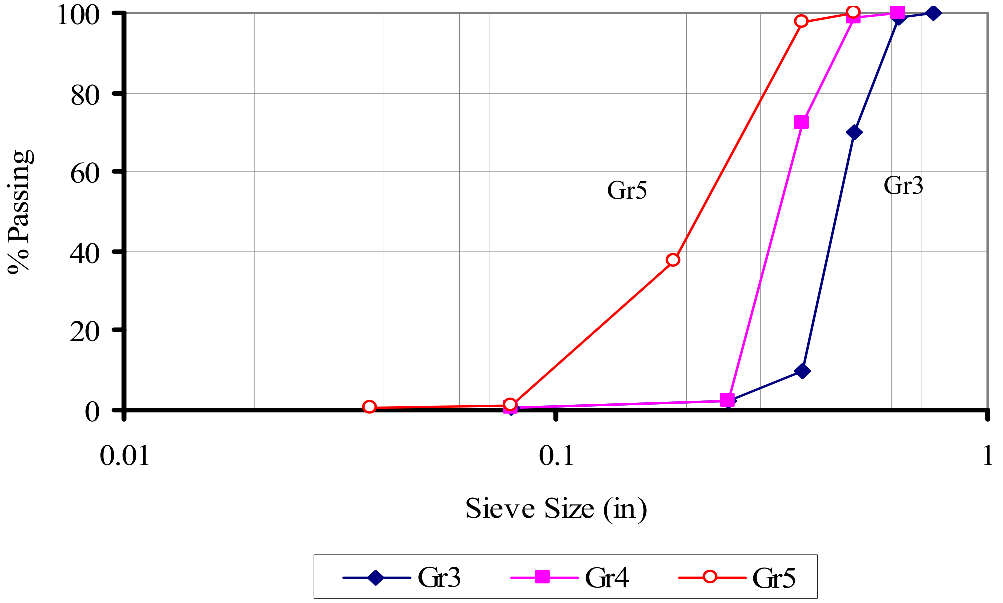


Figure 8. Aggregate Gradations for Limestone, Gravel, and Sandstone Aggregates.

Gradations Gr3 and Gr5 are more coarse and fine, respectively, compared to Gr4, which is more well graded (*5*). Finer gradations are often associated with bleeding, and coarser gradations tend to be more susceptible to degradation (*10,12*), particularly under heavy traffic loading. Most of the selected HSs (64.5 percent) used Gr4 aggregate (Table 8). Only one HS used Gr5 aggregate. Figure 7 also shows that the gradations for the lightweight aggregate are relatively more uniform compared to those shown in Figure 8 for limestone, gravel, and sandstone (*33,41*).

Overall, most of the HSs (49 percent) used *Gr4-P-A2* aggregate (grade 4 precoated limestone). Eleven percent of the HSs used *Gr4-U-A1* aggregate, all with emulsion (CRS-2P and CRS-2H) as the binder. Four percent had *Gr4-U-A3* aggregate with AC5-2% latex (Appendix C).

TRAFFIC

In this project, the traffic parameter considered in the experimental design was volume in terms of the average daily traffic (ADT) (*10,11,12,32,33,40,42*). This is consistent with the TxDOT surface treatment design procedure in terms of the binder and aggregate application rates

(*32,39*). Further dividing the traffic factor into speed, axle weights, or tire inflation pressure would have resulted in a more complex and lengthy analysis.

Traffic volume is one of the main criteria considered when selecting surface treatment binders. On high volume highways, particularly those with heavy traffic, an appropriate binder needs to be selected with the potential to rapidly develop sufficient structural strength within the critical 24 to 48 hour period after spraying to hold the aggregate in place (*12*).

For simplicity, researchers categorized ADT into two groups, high (T1) and low (T2) with an ADT of 3000 as the threshold value. This threshold value was based on design ADT limits obtained from selected TxDOT districts. The majority (62 percent) of the HSs in this project had category T2 ADT (Appendix C).

CHAPTER 4. TYPICAL VALIDATION RESULTS

Typical laboratory testing and field performance monitoring results are discussed in this chapter. A summary of all the laboratory and SCI field performance results are included in Appendices I, J, and L. Digital images of selected HSs and the distresses observed in the field are also included in Appendix K.

BINDER VISCOSITY TEST RESULTS

The viscosity results are plotted in Figure 9, with the binder viscosity on the left vertical axis and the temperature at which the viscosity was attained on the right vertical axis. The results are a mean representative of three measurements per binder sample, and the standard deviations ranged between 0.000 Pa·s and 0.005 Pa·s.

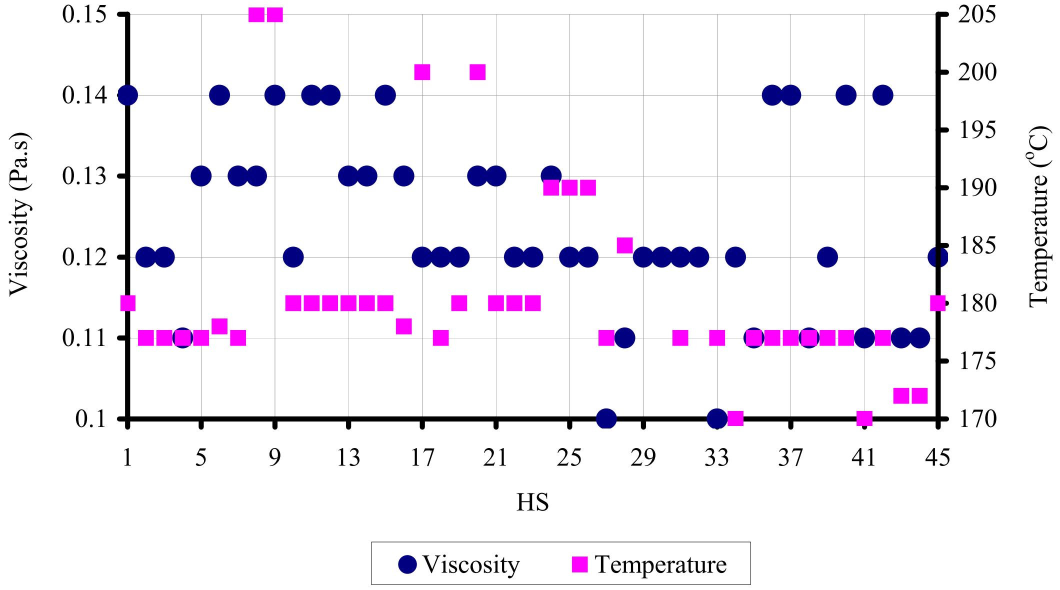


Figure 9. Brookfield Viscosity Results.

Figure 9 shows that all the binders met the recommended 0.10 to 0.15 Pa·s viscosity within a temperature range of 170 to 205 °C ($T_{\text{mean lab}}$ = 181 °C), consistent with the spraying temperature ($T_{\text{mean spray}}$ = 182 °C) for the asphalts. The mean field spraying temperature for asphalts on the selected HSs was approximately 182 °C with some as high as 204 °C.

These results also correlate with the kinematic viscosity reported by Kari et al. (*10*). However, the results cannot be directly related to the spraying properties of emulsions that include water and are sprayed at relatively lower temperatures. From the selected HSs, most of the emulsions were sprayed at a temperature of approximately 79 °C. Generally, an optimum binder temperature is required to ensure optimum binder viscosity and adequate aggregate embedment at the time of construction to minimize aggregate loss.

Initially during development of the SPG specification (*1,2*), the maximum value for attaining a binder viscosity of 0.10 to 0.15 Pa·s was set at 180 °C (Table 1) based on testing of a limited number of asphalts. This value was selected to avoid alteration of the binder chemical properties including degradation of the modifiers. Early in the validation phase of the project, researchers observed that some modified binders required heating up to 205 °C for the viscosity to be within the 0.10 to 0.15 Pa·s recommended range. The SPG limit was therefore modified to 205 °C in the final proposed specification (Appendix A) to reflect field conditions.

From the field data that had been gathered, the average pavement surface temperature for most of the HSs at the time of construction was 37 °C for the asphalts and 29 °C for emulsions. These values match reasonably well with the temperatures recommended by TxDOT (*5*), Wegman (*9*), and Kari et al. (*10*) and suggest that pavement temperatures at the time of construction did not contribute to poor performance.

BINDER SPG GRADING RESULTS

Based on the findings in the first phase of the project, researchers established 0.75 kPa as the $G^*/Sin\ \delta$ threshold value at the higher temperature limit in the SPG specification (Table 1) (*1,2*). During the initial validation phase, this value was revised to 0.65 kPa to include binders that were insignificantly below 0.75 kPa and had apparently exhibited adequate performance in the field. The revised final proposed SPG specification is subsequently attached as Appendix A.

Of the 45 HSs, 76 percent (34/45) of the SPG graded binders passed the pavement surface temperature criteria (i.e., met the environmental demand at 98 percent reliability) and 24 percent (11/45) failed. These results are graphically shown in Figure 10 and are summarized in Appendix I. Based on the hypothesis of the SPG validation principle, passing and failing implies adequate and inadequate performance in the field, respectively. Passing should match adequate performance and failure should correlate with inadequate performance. Otherwise, the specification is invalid.

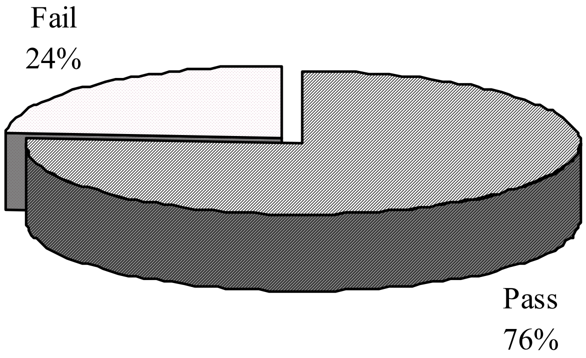


Figure 10. SPG Test Results.

Researchers recorded most of the sections passing the SPG criteria with PG 76-16, AC10-2% latex, AC15-P, CRS-2P, CRS-2H, and AC15-5TR binders. All AC10-2% latex, CRS-2P, CRS-2H, and AC15-P materials passed the SPG specification. Of the total eighteen AC15-5TR samples, only four failed, representing a 78 percent pass rate for the SPG specification. Only one out of the seven PG 76-16 samples failed.

With a revised $G^*/Sin\ \delta$ limit of 0.65 kPa (Appendix A), the majority of the failures were recorded with the AC5-2% latex material. In fact, only one out of the seven AC5-2% latex binder samples passed. Of the total eleven binder samples that failed, six were AC5-2% latex (HS34, HS35, HS41, HS42, HS43, and HS44), predominantly at the higher temperature limit, as evident in Appendix I. Four failures were AC15-5TR binders, two (HS2 and HS13) at the lower temperature limit and the other two (HS39 and HS40) at both higher and lower temperature limits. One was a PG 76-16 (HS27), which failed at the lower temperature limit mainly due to the 3 ^{o}C binder grade increment.

Note that in contrast to the generalized average TxDOT district temperature ranges in Figure 6 (Chapter 3) and Appendix C, the temperature ranges in Appendix I represent average temperature values obtained from the closest weather station to a particular HS. For SPG analysis, temperatures from weather stations closest to a given HS as listed in Appendix I were used

Effects of Binder Type on SPG Grading

Generally, AC15-5TR materials, followed by AC10-2% latex, PG 76-16, and AC15-P exhibited superior SPG grades in terms of the measured temperatures at the prescribed SPG threshold values. The highest and lowest SPG grade temperatures measured for AC15-5TR were 70 and -22 ^{o}C, respectively. An SPG grade temperature as low as -25 ^{o}C was measured for the AC10-2% latex. On the higher temperature limit, the lowest measured SPG grade temperature was 55 ^{o}C for AC5-2% latex. The highest measured on the lower temperature limit was -13 ^{o}C for an AC15-5TR. However, this difference in the SPG grades among different binder types may not be directly equated to field performance, which is a function of many other influencing factors.

The AC5-2% latex material constituted 55 percent of the total number of binders that failed the SPG specification. An extract from Appendix I for this binder is shown in Table 9.

Table 9. Examples of SPG Binder Grade Failures.

HS	Binder			Environment (^{o}C)	Comment
	Designation	Type	SPG Grade		
HS34	B3	AC5-2% Latex	SPG 58-16	65-23	Failed at both higher and lower temperature limits
HS35	B3	AC5-2% Latex	SPG 58-16	65-23	
HS41	B3	AC5-2% Latex	SPG 55-19	67-19	Failed at higher temperature limit
HS42	B3	AC5-2% Latex	SPG 58-19	67-19	
HS43	B3	AC5-2% Latex	SPG 58-22	67-20	
HS44	B3	AC5-2% Latex	SPG 58-22	69-21	

No satisfactory reasons were established for the failure of these AC5-2% latex materials. However, adequate performance was recorded in the field as discussed in this chapter. Researchers believe that the particular AC5-2% latex binder samples obtained were possibly of poor material quality. The latex type and characteristics used in modifying the AC5, the effects of transportation and storage, or the high SPG threshold values for this particular binder type were also considered other probable causes of this binder's failure to meet the SPG specification.

However, the binder grades shown in Table 9 are within the same margins as the PG and SPG standard grades for AC5 and AC5 with latex reported in Research Report 1710-1 (*1*,*2*). Nonetheless, researchers recommend further laboratory testing and SPG grading of this binder with particular emphasis on samples obtained directly from suppliers so as to establish confident benchmarks for the SPG grades of this material.

Effects of Binder Supplier on SPG Grading

Based on results from Appendix I, some similar binder types from different suppliers graded differently in the SPG specification. A typical example is shown in Table 10 for AC5-5TR.

Table 10. Example of Binder Supplier Effect on SPG Grading.

HS	Binder				Comment
	Designation	Type	Supplier	SPG Grade	
HS1	B1	AC15-5TR	BS2	SPG 70-16	Binder grades different for same type from different suppliers
HS2	B1	AC15-5TR	BS1	SPG 67-13	

Researchers attributed the different binder grades to the differences in modifiers (e.g., the type of tire rubber used), manufacturing process, and quality control methods between the suppliers. In some instances, such grade differences for the same binder may be necessary to account for the variation in specific traffic levels, environmental conditions, aggregate type and characteristics, or existing pavement conditions.

These results show that binder supplier has an effect on the SPG binder grades and may impact performance. From Table 10, it can also be hypothesized that for this particular case, the AC15-5TR supplied by supplier BS2 was a higher grade quality than that from supplier BS1. The AC15-5TR binder grade SPG 70-16 may sustain more extreme environmental temperatures than the AC15-5TR binder grade SPG 67-13. However, this binder grade difference may not directly impact the field performance rating, which is a function of many other factors.

Environmental Temperatures and Binder Grade Increment

During the analysis described in Chapter 5, researchers discovered that some binders failed the SPG specification primarily due to the 3 ^{o}C grade increment. The PG 76-16, for example, on HS27 with an SPG grade of SPG 67-16 failed at the lower temperature limit (-19 ^{o}C) in an environment of 66-18 ^{o}C at 98 percent reliability but passed when tested at -18 ^{o}C ($S < 500$ MPa and $m\text{-}value > 0.24$). However, researchers could not grade this binder as SPG 67-18 because the 3 ^{o}C temperature increment does not include this limit (-18 ^{o}C) in the grading system. So the binder is instead graded as SPG 67-16, which indicates failure at the lower temperature limit, though in reality it meets the environmental temperature demand. So although the SPG specification shows failure, actual field performance could be adequate. As discussed subsequently, HS27 performed relatively well with an overall SCI score greater than 70 percent. However, a poor-quality binder sample could also have been the reason for failing the SPG specification, since all the other PG 76-16 samples passed the specification.

FIELD PERFORMANCE MONITORING RESULTS

As shown in Figure 11, 82 percent (37/45) of the HSs exhibited adequate performance (SCI equal to or greater than 70 percent) both in terms of aggregate loss and bleeding and as combined distresses. Eighteen percent (8/45) exhibited inadequate performance (SCI less than 70 percent).

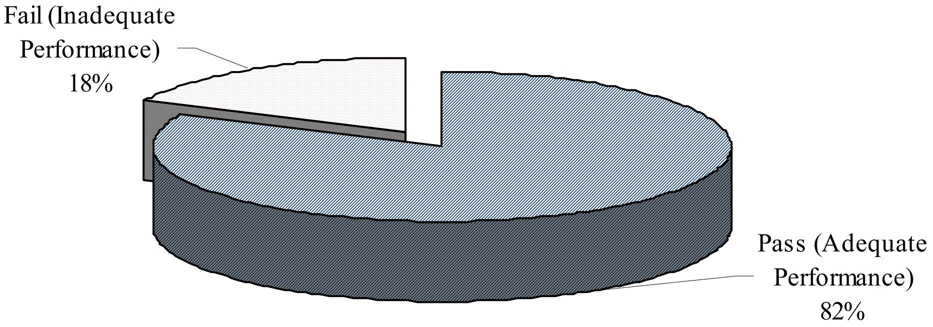


Figure 11. Field Performance Monitoring Results.

As discussed previously, performance evaluation and rating for this validation project was based on the SCI criteria with 70 percent SCI score as the threshold value defining pass and failure in terms of adequate and inadequate performance, respectively. This section presents some typical examples of adequate and inadequate performance in relation to the binders used. More examples are illustrated in Appendices J, K, and L.

In subsequent subsections, other factors with a direct or indirect impact on surface treatment performance are also discussed. These include environment, aggregates, traffic, and existing pavement conditions prior to the surface treatment. Again, design, construction, and quality control processes were outside the scope of this initial validation project.

Example of Adequate Performance, SCI ≥ 70 Percent

With a few exceptions, almost all the binders exhibited adequate performance (Appendix J). Under relatively similar conditions, the decreasing rank order of performance was PG 76-16, AC10-2% latex, AC15-P, AC15-5TR, CRS-2P, AC5-2% latex, and CRS-2H. In fact, researchers recorded no significant distresses on most of the PG 76-16 HSs. Figures 12 and 13 show an example of adequate (Pass) performance for HS6 both in terms of the SCI analysis and the digital picture.

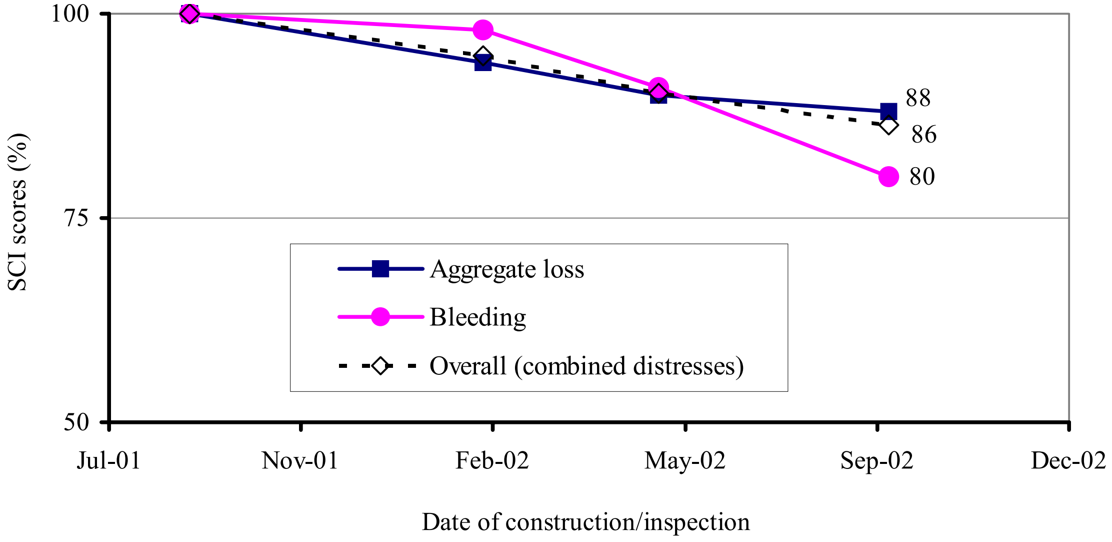


Figure 12. Example of Adequate Performance on HS6 – SCI Analysis.

Figure 13. Example of Adequate Performance on HS6 – Pictorial.

The SCI plot shows that performance is adequate both in terms of the individual distresses and overall combined distresses with SCI scores greater than 70 percent. The overall SCI score is 86 percent. This is further evident in the digital picture in Figure 13. Materials used on this HS were AC15-5TR binder (SPG 70-19) in an environment of 65-15 ^{o}C at 98 percent reliability and Gr4 precoated lightweight aggregates. The ADT was approximately 5500 with a speed limit of 45 mph.

Example of Inadequate Performance, SCI < 70 Percent

All eight HSs where inadequate (Fail) performance was recorded utilized AC15-5TR binder (Appendix J). Figures 14 and 15 show an example of inadequate performance in terms of aggregate loss (SCI_{AL} = 60 percent) for HS7.

HS7 used AC15-5TR (SPG 70-19) in an environment of 65-14 ^{o}C at 98 percent reliability and Gr3 precoated lightweight aggregates. This HS has an ADT of approximately 7400 with a speed limit of 70 mph. More details are included in Appendices C, J, and L.

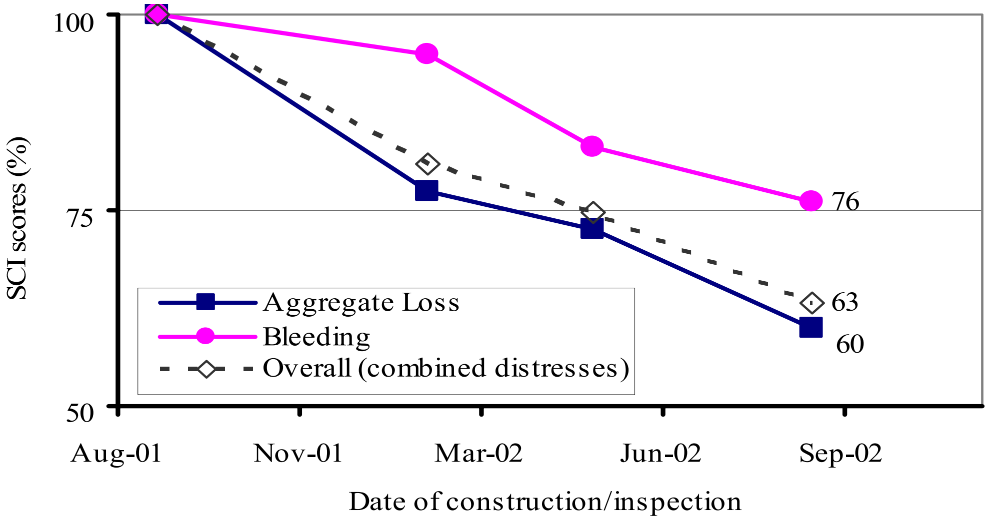


Figure 14. Example of Inadequate Performance on HS7 – SCI Analysis.

Figure 15. Example of Inadequate Performance on HS7 – Pictorial.

Distresses, Binders, and the Environment

During performance monitoring, researchers observed that where emulsions and AC15-P were used, the predominant distress was aggregate loss. The AC15-5TR sections primarily exhibited bleeding.

Researchers also observed that most of the distresses occurred at the high pavement service temperatures in the summer, with a general trend of stabilization or improvement toward winter as the pavement temperatures gradually decreased. A typical example for CRS-2H on

HS29 is shown in Figure 16. This was the general performance trend for most of the CRS-2H HSs.

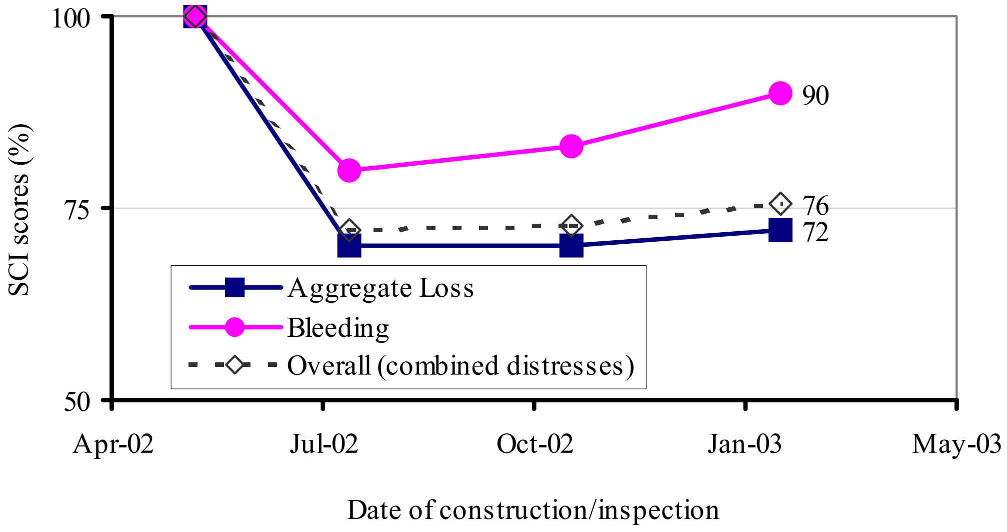


Figure 16. Example of Improving Performance of CRS-2H on HS29.

In particular, bleeding was often more prevalent in the summer than in the winter. This is expected, as the binder is more susceptible to flow at higher pavement service temperatures, especially under high ADT or if too much binder was applied at the time of construction (*8,12,13,16,29,30*). Where aggregate loss occurred, it was often more prevalent just after construction, probably due to traffic whip-off (*40*), and in the winter at low service pavement temperatures.

Whereas some HSs like HS29 (Figure 16) exhibited improving performance with time, the general trend of most of the HSs with inadequate performance was deterioration with time due to binder aging, increase in traffic, and changes in environmental conditions. Figure K9 in Appendix K for HS2 is a typical example.

Effects of Aggregates on Performance

For any given binder type and SPG grade, limestone and gravel exhibited superior performance compared to lightweight and sandstone. Also, the uncoated gravel, apparently due to relatively low ADT, performed better than most of the precoated aggregates (lightweight, limestone, and sandstone) in contrast to the uncoated lightweight, which performed poorly.

However, researchers observed that for the same aggregate type and under similar traffic, environmental, and existing pavement conditions, precoated aggregates generally performed better than uncoated aggregates. This is the expected performance trend and explains why most HSs used precoated aggregates (*10,33,39,40*).

With regard to aggregate gradations, researchers found that for any given SPG binder grade, aggregate Gr3 was predominantly associated with raveling and Gr5 with bleeding (*12*), while Gr4 tended to be associated with both of these distresses. Under relatively similar conditions, the decreasing rank order of performance was Gr4, Gr3, and Gr5.

Effects of Traffic on Performance

Generally, there was more distress on high-volume highways (ADT equal to or greater than 3000 [T1]), particularly in the outside lanes with slower and heavier traffic (*12*). Bleeding was the predominant distress associated with high ADT and heavy axle weights (trucks). This distress was often more severe in the outside than the inside wheelpath, particularly with the AC15-5TR material. Where this was observed, aggregate embedment too was usually high in the outside wheelpath. Figure 17 shows an example of bleeding in the outside lane of HS11.

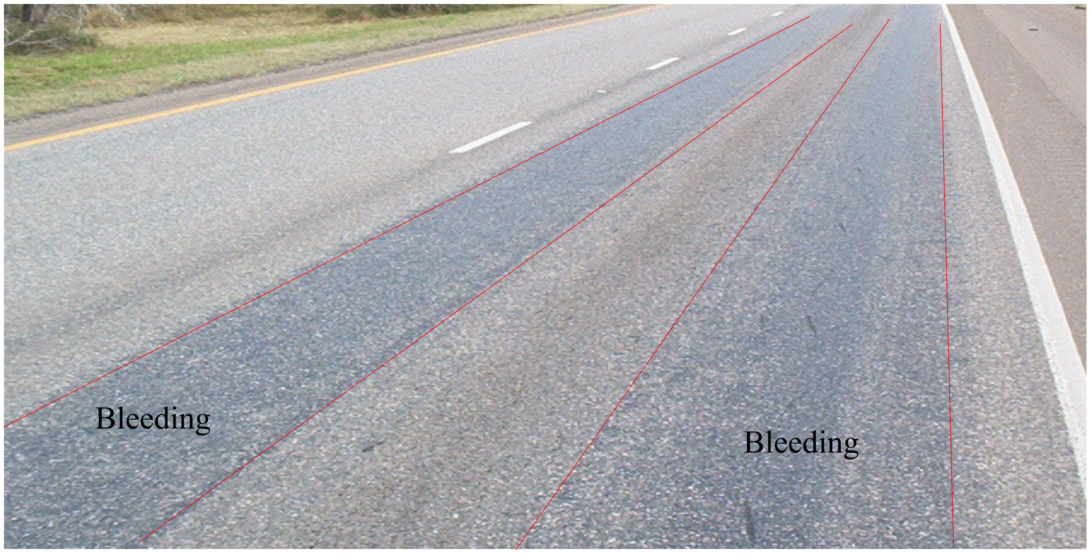


Figure 17. Bleeding in the Outside Wheelpath of HS11 (SCI_{BL} = 57 Percent).

The materials used on HS11 were an AC15-5TR (SPG 70-13) in an environment of 69-10 °C at 98 percent reliability and Gr4 precoated limestone aggregates. This HS has an ADT of approximately 9800 with a speed limit of 70 mph.

Although there was no significant distress on the inside lane, the outside lane exhibited severe bleeding in the wheelpaths, as evident in Figure 17, due to the high ADT (9800) and possibly slow channelized heavy axle-weight trucks using the outside lane. Performance was inadequate in terms of bleeding with a SCI score of 57 percent (Appendices J, K, and L). During analysis (Chapter 5), researchers discovered that this was also a design- and/or construction-related problem in which the binder application rate was not appropriately varied/adjusted for the high traffic level in the outside lane and the wheelpaths (*33,37,40,42,43*).

Effects of Existing Pavement Condition on Performance

Cracking of the underlying structure was one of the pre-existing pavement conditions researchers believed had an impact on surface treatment performance and distresses, and therefore this factor indirectly impacted the validation of the specification (*12*).

HS1, HS8, HS39, and HS40 exhibited longitudinal and transverse cracks. A pictorial example is shown in Figure 18 for HS1.

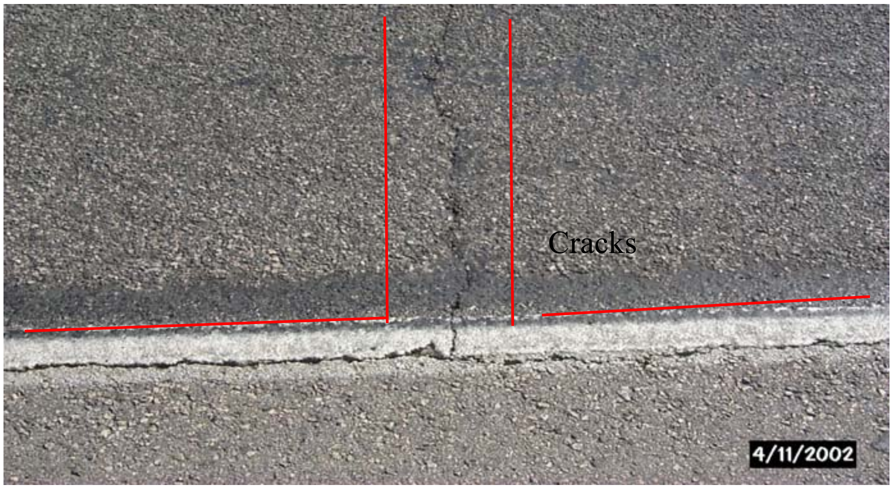


Figure 18. Example of Longitudinal and Transverse Cracks on HS1.

These cracks were more pronounced particularly in the winter at colder pavement service temperatures. In the summer, the binder tended to flow and heal the cracks.

In their analysis described in Chapter 5, researchers found that most of these HSs with cracks also exhibited inadequate performance in terms of aggregate loss and bleeding. For example, HS1, HS39, and HS40 had SCI scores less than 70 percent (Appendices J, K, and L).

AGGREGATE EMBEDMENT

For most of the HSs, aggregate embedment ranged between 40 percent and 80 percent in the wheelpath (often higher in the outside wheelpath) and 20 percent to 60 percent between the wheelpaths. Generally, embedment was higher for Gr5 aggregates compared to Gr4 and Gr3 (often the lowest) aggregates. Also, high aggregate embedment was generally associated with bleeding and low embedment with aggregate loss (*9,33*). With regard to traffic, aggregate embedment was often high on HSs with high ADT (T1), heavy axle weights, and relatively low traffic speed.

CHAPTER 5. ANALYSIS OF RESULTS

This chapter presents a comparative analysis of the laboratory (SPG specification) and field performance results. A reliability analysis and a list of standardized SPG binder grades are also included.

THE SPG SPECIFICATION VERSUS FIELD PERFORMANCE

There was a good correlation between the SPG binder grade predictions and actual field performance for 78 percent (35/45) of the HSs. This is shown in Figure 19. Of these, 89 percent registered adequate performance and 11 percent inadequate performance.

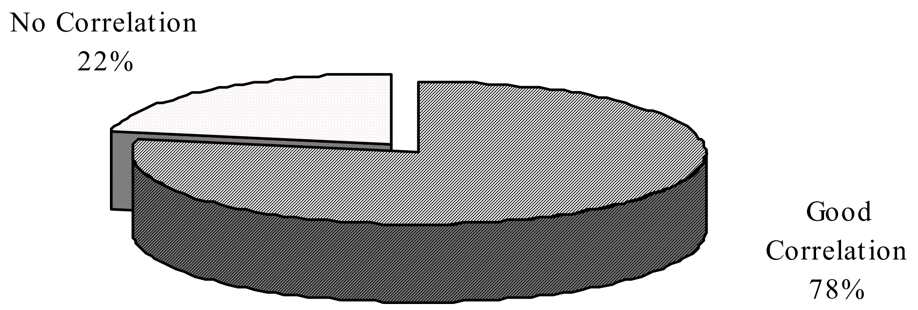


Figure 19. Analysis - SPG versus Field Performance.

However, the results for 22 percent (10/45) of the HSs did not correlate (Figure 19), mostly with AC15-5TR and AC5-2% latex binders. The SPG specification predicted the opposite of measured field performance. For 40 percent (4 HSs) of these, the SPG predicted adequate performance while actual field performance was inadequate. For the remaining 60 percent (6 HSs), field performance was actually adequate (SCI greater than 70 percent) in contrast to the SPG binder grade predictions. These results are summarized in Table 11 and are discussed in subsequent subsections.

Table 11. Tabulated Summary of SPG-Field Performance Results.

	SPG – Field Performance	# of HSs	% of 45 Total HSs	
Good Correlation	Pass – Pass (SCI ≥ 70%)	31	69	78
	Fail – Fail (SCI < 70%)	4	9	
No Correlation	Pass – Fail (SCI < 70%)	4	9	22
	Fail – Pass (SCI ≥ 70%)	6	13	
Total		45	100	100

In this validation project, a Pass as indicated in Table 11 for the SPG specification refers to a binder meeting the environmental temperature demand at a given reliability level in a prescribed location (e.g., a binder grade of SPG 70-13 in an environment of 69-10 ^{o}C at 98 percent reliability). A Fail refers to failure of the binder to meet the environmental temperature demand at a given reliability level in a prescribed location (e.g., a binder grade of SPG 58-16 in an environment of 65-23 ^{o}C at 98 percent reliability). This means that at that prescribed design reliability, the binder type and/or grade is not suitable for use in that particular environment. During laboratory testing and grading of the binders, Pass and/or Fail were determined in terms of the specified SPG threshold values ($G^*/Sin\ \delta$, S, and *m-value*) relative to the given environment and reliability level (Table 1 and Appendix A).

For field performance monitoring, a Pass (Table 11) refers to adequate performance of an HS with insignificant or no visual distress and SCI scores equal to or greater than 70 percent. A Fail means inadequate performance with distresses and SCI scores less than 70 percent. In this regard, performance failure of an HS was determined in terms of either aggregate loss (i.e., SC_{AL} less than 70 percent) or bleeding (i.e., SC_{BL} less than 70 percent) or a combination of both aggregate loss and bleeding (i.e., $SCI_{Overall}$ less than 70 percent).

Based on these definitions of Pass and Fail, a good correlation (Table 11) or a match (agreement) between the SPG specification and field performance therefore implied either a Pass and a Pass (Pass-Pass), or a Fail and a Fail (Fail-Fail) in the SPG specification and field performance, respectively. Conversely, no correlation (Table 11) or disagreement could either be a Pass and a Fail (Pass-Fail) or a Fail and a Pass (Fail-Pass) in the SPG specification and field performance, respectively. A summary of the SPG-field performance results for all the HSs is attached as Appendix J.

EXAMPLES OF CORRELATIONS BETWEEN THE SPG SPECIFICATION AND FIELD PERFORMANCE

In this section, examples of good correlation and non-correlation between the SPG specification and field performance are discussed. Where the SPG and field performance results did not correlate, probable causes of the discrepancies and/or failures are also discussed.

Good Correlation: Pass (SPG) – Pass (Field Performance, SCI ≥ 70 Percent)

Figures 20 and 21 show an example of a match for adequate performance between the SPG grade prediction and actual field performance. From the binder grading results, the SPG specification predicted adequate performance (Pass), which was consistent with actual observed field performance (Pass). The SPG grade for the AC15-P binder used on HS20 in an environment of 67-16 ^{o}C at 98 percent reliability was SPG 67-16. This is a Pass in terms of the SPG specification and predicts adequate performance in the field. As evident in Figure 20, performance was adequate with an overall SCI score of 97 percent, and this result correlates with the SPG binder grade prediction. Similar results were also observed for 30 other HSs, including one (HS45) with AC5-2% latex material (Appendices J and K).

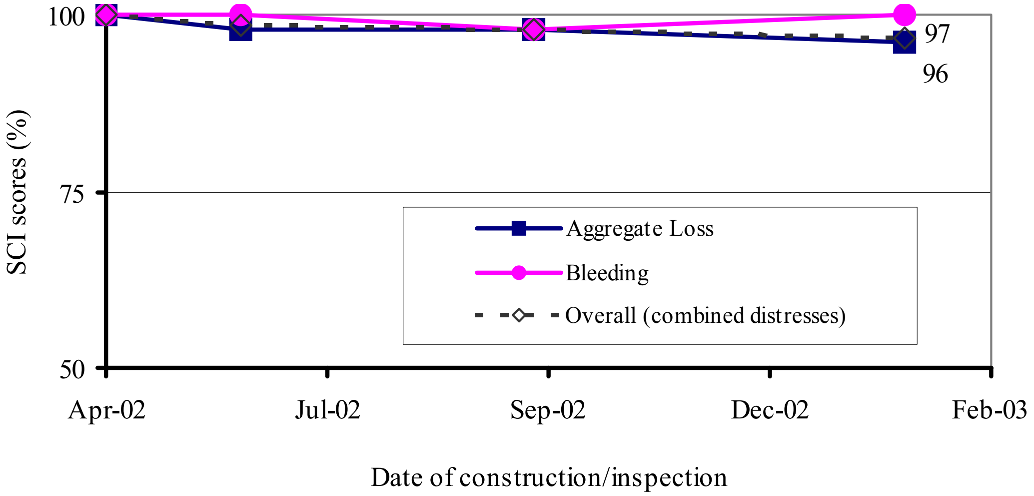


Figure 20. Adequate Performance on HS20 – SCI Analysis ($SCI_{Overall}$ = 97 Percent).

Figure 21. Adequate Performance on HS20 – Pictorial.

The aggregate used on HS20 was Gr4 precoated limestone. The ADT is approximately 3500 with a speed limit of 45 mph. Material application rates were 0.34 gallons per square yard (gal/sy) of binder sprayed at 193 ^{o}C and 1/113 cubic yard per square yard (cy/sy) of aggregate with a pavement surface temperature of 52 ^{o}C at the time of construction. These design and construction parameters are consistent with TxDOT recommendations (*33,40*).

Good Correlation: Fail (SPG) – Fail (Field Performance, SCI < 70 Percent)

For four HSs (HS2, HS13, HS39, and HS40) (Appendix J), the SPG specification predicted inadequate performance (Fail), which was also observed during field performance monitoring (Fail) and evident from the SCI analysis. Thus, there was a match between the SPG binder grade prediction and actual field performance. All of these HSs utilized AC15-5TR binder. Essentially, the binders failed to meet the environmental temperature demand during SPG grading and also failed in terms of field performance with SCI scores less than 70 percent. SCI graphs and images of distresses are provided in Appendix K.

An example of failure both in the SPG specification and actual field performance is shown in Figures 22 and 23 for HS39. The binder used was an AC15-5TR grade SPG 58-22 in an environment of 64-26 ^{o}C at 98 percent reliability. Clearly, this is a Fail in terms of the SPG specification and indicates inadequate performance in the field, which is evident in Figures 22 and 23 with an overall SCI score of 54 percent. Aggregate loss was more predominant than bleeding. However, both distresses appeared to increase with time as seen in Figure 22.

The aggregate used on HS39 was Gr3 precoated limestone, and the HS has an ADT less than 3000 with a speed limit of 70 mph.

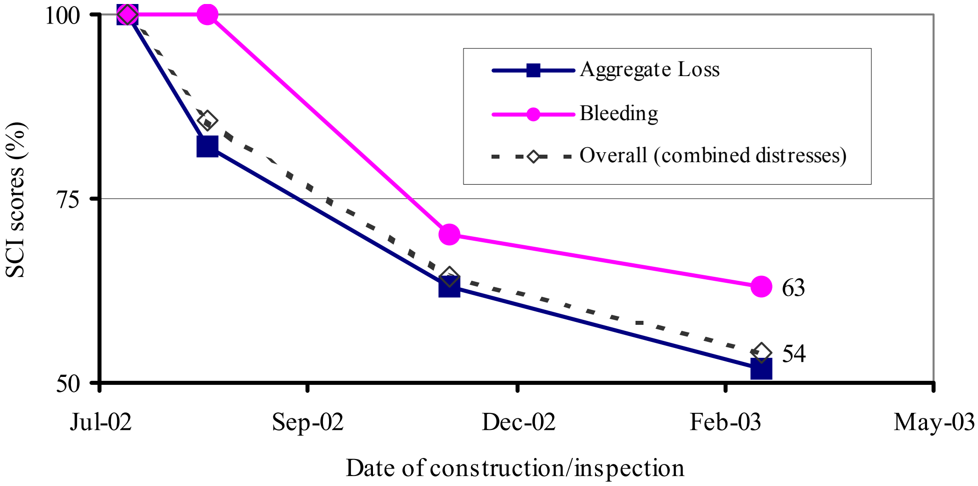


Figure 22. Inadequate Performance on HS39 – SCI analysis ($SCI_{Overall}$ = 54 Percent).

Figure 23. Inadequate Performance on HS39 – Pictorial.

Besides the binder, researchers felt that design, construction, and quality control processes including the existing pavement condition also contributed to the inadequate performance of these HSs (HS2, HS13, HS39, and HS40). Some of these details are tabulated in Appendix L.

For HS39, the existing pavement structure appeared to have been structurally cracked. This cracking could have indirectly contributed to the HS's inadequate performance. The material application rates were 0.59 gal/sy of binder and 1/100 cy/sy of aggregate. These rates are consistent with TxDOT district recommendations (*32,39*). Thus, construction and poor workmanship appear to have been the possible contributing factors to the poor performance of HS39.

No Correlation: Pass (SPG) – Fail (Field Performance, SCI < 70 Percent)

For four AC15-5TR HSs (HS1, HS7, HS11, and HS12) (Appendix J), there was disagreement between the SPG binder grade predictions and actual observed field performance. The results did not correlate. The binders passed the SPG specification (Pass) but exhibited inadequate performance in the field (Fail). Despite meeting the environmental temperature demand during SPG grading, all these HSs had SCI scores less than 70 percent. Primarily, all failed due to bleeding except HS7, which had a SCI score of 60 percent for aggregate loss and 76 percent for bleeding. Details for these HSs are provided in Appendices J, K, and L.

An example of a Pass in the SPG specification and Fail (inadequate performance) in the field is shown in Figures 24 and 25 for HS1. The SCI graph shows progressively deteriorating performance with time. The HS failed predominantly due to excessive bleeding, particularly in the wheelpath during the summer season. Aggregate loss was also evident but was not as severe as bleeding.

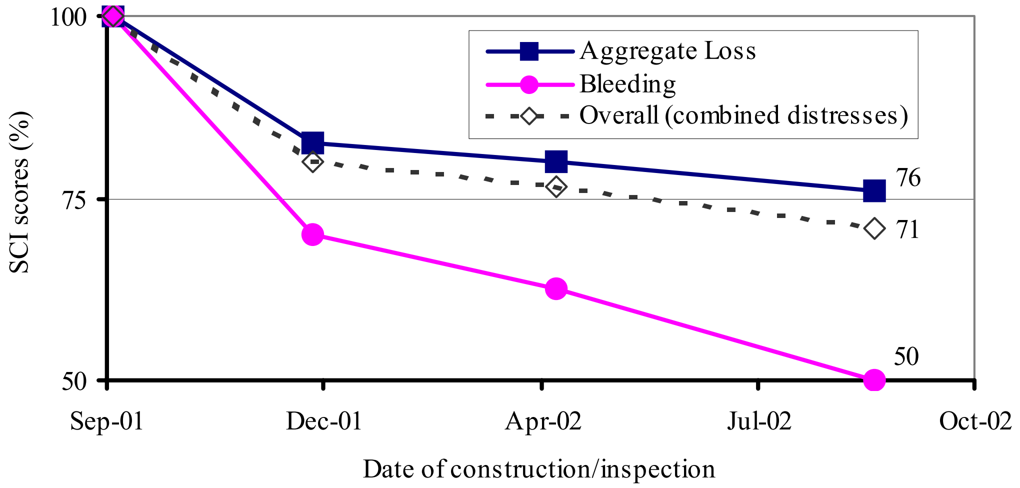


Figure 24. Inadequate Performance on HS1 – SCI Analysis (SCI_{BL} = 50 Percent).

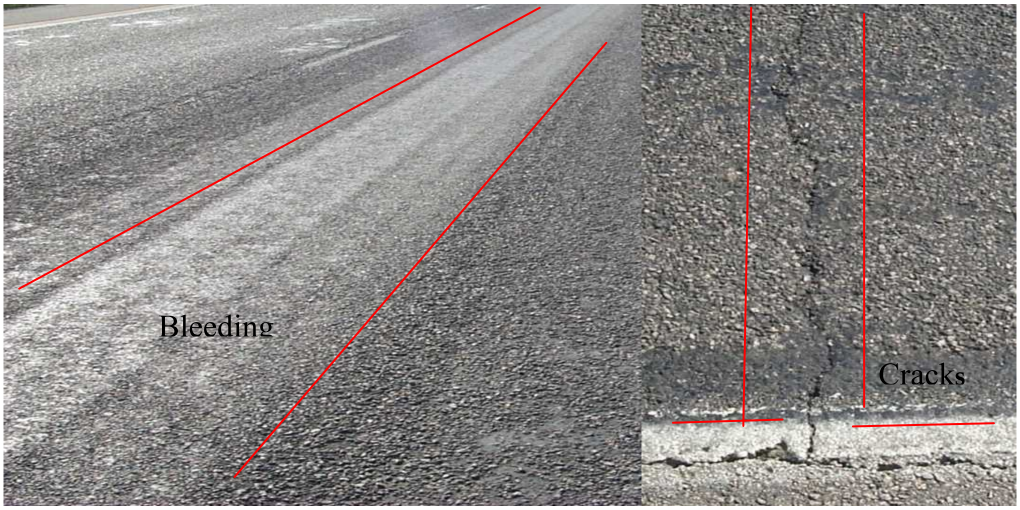


Figure 25. Inadequate Performance on HS1 – Pictorial.

The SPG grade for the AC15-5TR binder used on HS1 was SPG 70-16, which meets the environmental temperature demand of 66-16 ^{o}C at 98 percent reliability. The high ADT (19,260) compounded with heavy axle weights and channelized traffic evident from the high aggregate embedment (~90 percent) might have been a contributing factor to the excessive bleeding in the wheelpaths. As can be seen in Figure 25, transverse and longitudinal cracks were also evident on this HS. These cracks also could have indirectly impacted the performance of HS1.

No Correlation: Fail (SPG) – Pass (Field Performance, SCI ≥ 70 Percent)

This discrepancy was observed mostly with HSs utilizing AC5-2% latex material (Appendix J). Out of seven, laboratory and field results did not correlate for six of these HSs (HS34, HS35, HS41, HS42, HS43, and HS44). Details are provided in Appendices K and L. Although the binder samples failed the SPG specification (Fail) (i.e., did not meet the environmental temperature demand at 98 percent reliability), field performance was adequate (Pass) with SCI scores greater than 70 percent.

HS34, for example, had an overall SCI score of 84 percent (Figures 26 and 27), while the binder grade for the AC5-2% latex material was SPG 58-16 in an environment of 65-23 ^{o}C at 98 percent reliability. This is an obvious Fail in terms of the SPG specification, but unexpectedly a Pass (adequate) in terms of field performance.

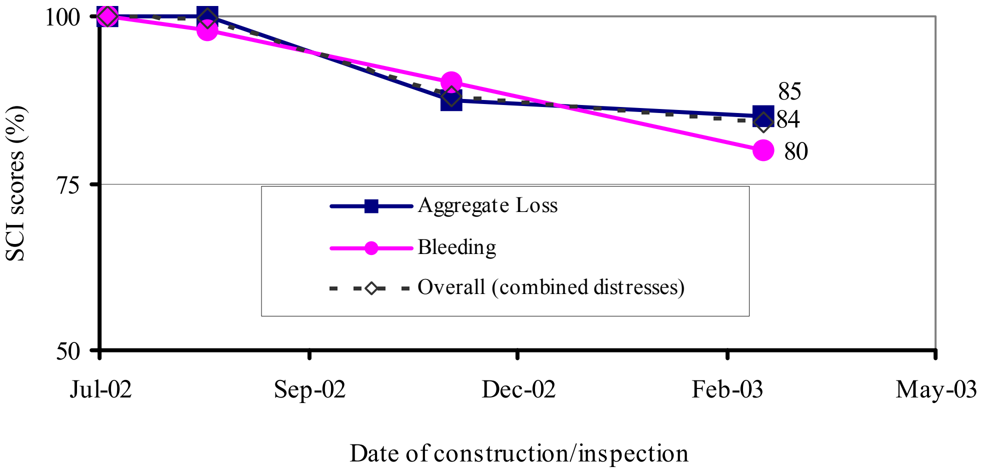


Figure 26. Adequate Performance on HS34 – SCI analysis ($SCI_{Overall}$ = 84 Percent).

Figure 27. Adequate Performance on HS34 – Pictorial.

The aggregate used on HS34 was Gr4 uncoated river gravel. The ADT is approximately 260 with a speed limit of 70 mph. Material application rates were 0.46 gal/sy of binder, sprayed at 174 ^{o}C, and 1/110 cy/sy of aggregate.

As discussed in Chapter 4, the possible causes of this discrepancy was the sampled material being of poor quality, the modifier (latex), and the SPG limits. The inconclusiveness of the results for this material (AC5-2% latex) calls for more laboratory testing of these binders.

However, the reason for the adequate field performance could be due to the relatively low ADT on these HSs. HS34, for instance, has a very low ADT of 260. As evident from Appendix C, most of these HSs have ADT less than 3000. With time significant distresses and subsequent inadequate performance could be expected as traffic steadily increases and the stress on the pavement increases. Also, binder aging (with time) could negatively impact their performance. Nonetheless, verbal data gathered from the field suggested that AC5-2% latex binders are predominantly associated with bleeding, particularly in the summer at high pavement service temperatures.

RELIABILITY ANALYSIS AND THE SPG GRADE INCREMENT

Unlike the 7-day average for the maximum temperature value, the minimum (low) pavement surface temperature is only representative of a 1-day measurement (*1,2,7,8*). There is therefore a higher degree of variability for the lower temperature limit in the SPG grades. Consequently, a 3 °C grade increment results in a much smaller change in reliability at the lower than at the higher temperature limit. Researchers attained an equivalent change in reliability when the adjustment was 6 °C on the lower temperature limit and 3 °C on the higher limit. An example is shown in Figure 28 for an environment of 66-15 °C at 98 percent reliability. For this type of an environment, the minimum required binder grade at 98 percent reliability is SPG 67-16.

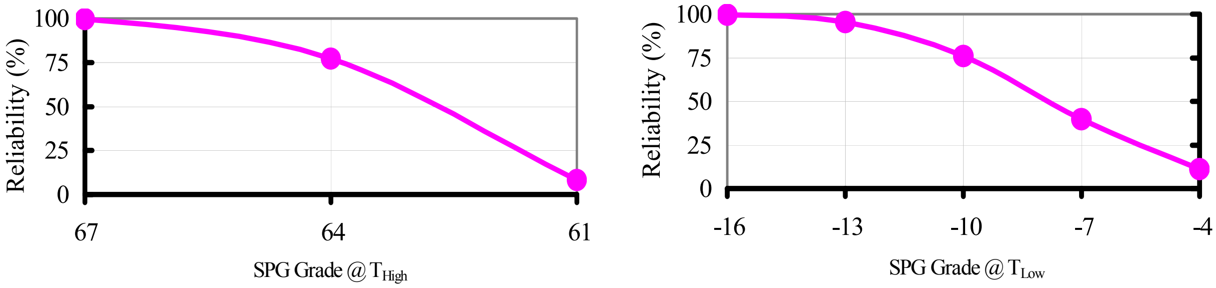


Figure 28. Reliability Analysis for an Environment of 66-15 °C.

For each SPG temperature value on the horizontal axis in Figure 28, reliability was backcalculated as a function of latitude and air temperature using the SHRP temperature models and statistical tables of standard normal distribution (*34,35,36*). Figure 28 clearly shows that to move from 100 percent reliability to about 75 percent for the higher temperature limit, a 3 °C change occurs from 67 to 64 °C. To attain this same change in reliability for the lower temperature limit, a 6 °C change must occur, from –16 to –10 °C (Figure 28). These calculations are summarized in Table 12.

Table 12. Reliability Analysis.

Environment @ 98 % Reliability = 66-15 °C, Required Binder Grade = SPG 67-16						
T_{High}	Reliability (%)	Δ* Reliability @ 3 °C (%)	T_{Low}	Reliability (%)	Δ Reliability @ 3 °C (%)	Δ Reliability @ 6 °C (%)
67	99.8	23.1	-16	99.6		23.6
64	77.0	69.0	-13	95	4.6	
61	8.0		-10	76	19.0	65.0
			-7	40	36.0	
			-4	11	29.0	

*Change

Table 12 shows that a temperature grade change of 3 and 6 °C for the higher and lower temperature limits, respectively, produces almost equivalent changes in reliability (i.e., 23.1 versus 23.6 or 69.0 versus 65.0). For this reason, researchers suggest that an SPG binder grade increment of 6 °C be used for the lower temperature limit to ensure a consistent change in reliability at both design temperatures. This is subsequently included in the final proposed SPG specification attached in Appendix A.

However, with the exception of the standardized binder SPG grades discussed subsequently, all the analyses in this initial validation project were based on a 3 °C grade increment both for the higher and lower temperature limits.

STANDARDIZED SPG BINDER GRADES

Based on the results of this initial validation project, researchers established standardized SPG binder grades as a function of binder type and environmental location at 98 percent reliability. These SPG grades were standardized based on 3 and 6 °C increment for the higher and lower temperature limits, respectively. The grades are shown in Appendix M, Table 13, and Figure 29.

Standardized SPG Grades Based on Binder Type

Appendix M is a summary of the standardized SPG grades for some of the binders used in this project including the binders reported in Research Report 1710-1 (*1*). These SPG grades are representative of all the different binder suppliers and environmental conditions considered in the project. The SPG grades are not exhaustive but provide guidance for SPG grading of binders.

Standardized SPG Binder Grades Based on Environmental Location

Using the average TxDOT district pavement surface temperatures at 98 percent reliability, researchers standardized the SPG binder grades into five Texas environmental zones shown in Figure 29. These zones (Dry-Cold, Wet-Cold, Dry-Warm, Wet-Warm, and Moderate) were based on an analysis by Freeman in ongoing TxDOT Project 0-187-06 (*44*). In this project, Freeman used annual precipitation, annual freezing index, and the number of wet days and freeze/thaw days to group the TxDOT districts into these five zones (*44*).

The grades in Figure 29 are merely a guide as to which SPG binder grades to use in a particular environmental zone. These standardized grades should also help suppliers to effectively narrow their SPG product lines.

From Figure 29, the SPG grades were further summarized into eight standardized SPG grades based on the overall Texas environmental conditions. These are shown in Table 13. However, the standardized SPG grades in Figure 29 and Table 13 were based on an assumed design reliability of 98 percent and are not exhaustive. Different SPG grades may be required for different reliability levels.

Table 13. Summary of Standardized SPG Binder Grades for Texas @ 98 Percent Reliability.

#	Standardized Binder Grade
1	SPG 64-16
2	SPG 67-10
3	SPG 67-16
4	SPG 67-22
5	SPG 67-28
6	SPG 70-16
7	SPG 70-22
8	SPG 70-28

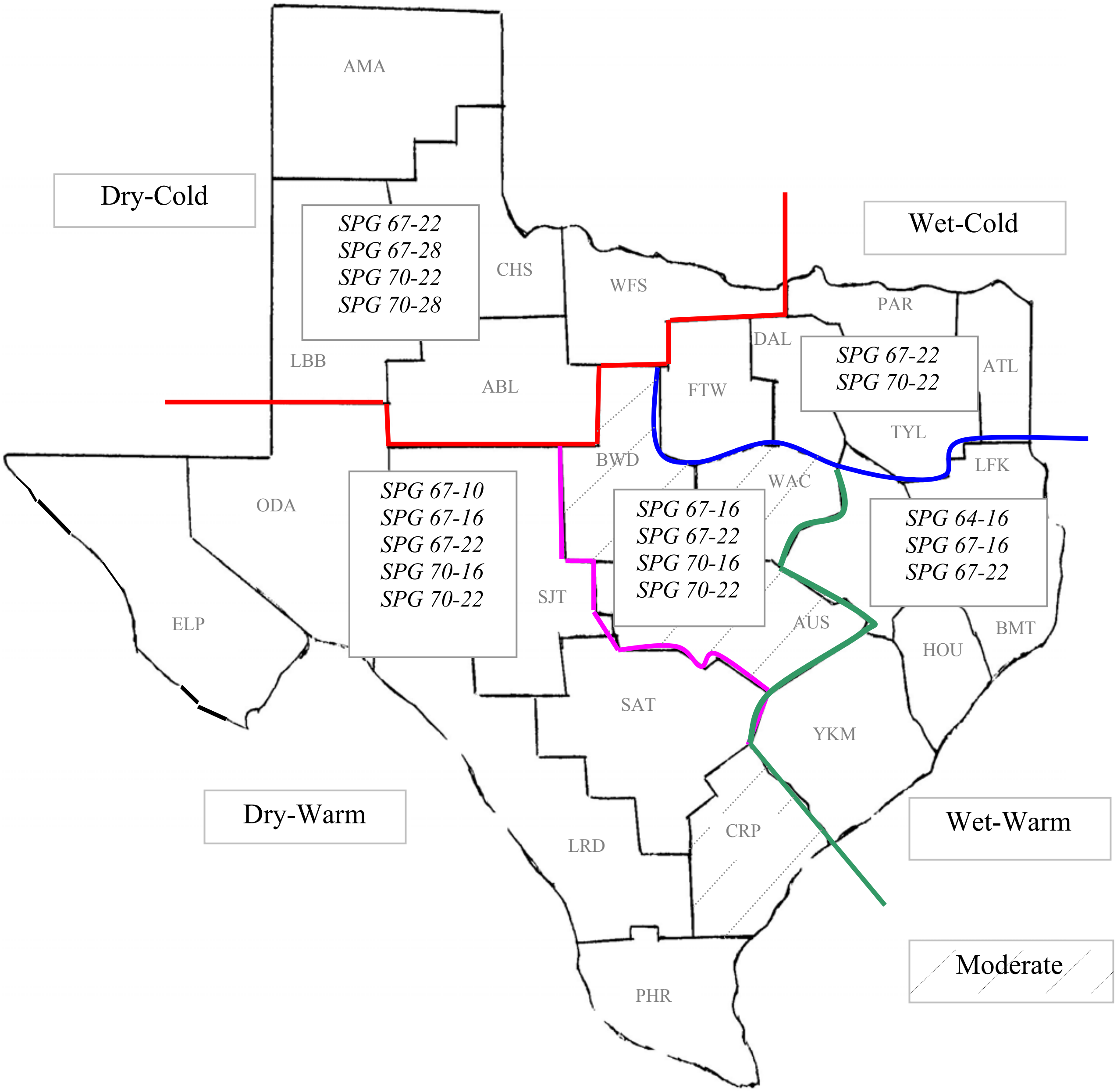


Figure 29. Standardized SPG Binder Grades for Texas Environmental Zones @ 98 Percent Reliability.

CHAPTER 6. DISCUSSION AND SYNTHESIS OF THE FINDINGS

Generally, the results of this initial validation project showed a good correlation between the proposed SPG specification and actual field performance. Considering that the HSs were randomly selected and that the researchers did not have control over their design and construction, the results are promising and are indicative that the proposed SPG specification is functional. However, there were some deficiencies in the specification leading to discrepancies between the SPG binder grade predictions and actual observed field performance for 22 percent of the HSs.

In this chapter, the general causes of discrepancies and failures in the SPG specification and field performance are discussed. These include materials and laboratory testing, SPG threshold values, SPG grading criteria, performance monitoring and evaluation criteria, design, and construction.

MATERIALS AND LABORATORY TESTING

Poor material quality, transportation and storage effects, and methods of characterizing the binder temperature properties were some of the factors considered to have affected the laboratory test results and, subsequently, the overall SPG validation process. These are discussed in this section.

Poor Material Quality

Researchers attributed some of the binders' failure to meet the SPG specification to the particular sampled binders being of poor material quality. One example was HS27; all the other PG 76-16 binder samples from the same supplier and tested within the same time period passed the SPG specification, while HS27 failed the lower temperature limit but exhibited adequate performance in the field (SCI greater than 70 percent).

Time, Transportation, and Storage Effects

Time lag between sampling and actual testing could be a potential source of erroneous results. Segregation and/or oxidation of the binder can possibly occur during transportation and storage. This can negatively impact the SPG grading process and produce incorrect results. Generally, the binders should be tested as soon as they are sampled; otherwise, they should be stored at cold temperatures to minimize aging due to oxidation.

For the AC5-2% latex material, failure was among other reasons either due to poor binder samples, the AC5-2% latex itself, or possibly transportation and storage effects prior to laboratory testing and SPG grading.

Characterization of the Binder Temperature Properties

Researchers used the PAV and BBR tests (Appendix A) to characterize the low-temperature properties of the binders (*1,2,7,8*). According to chemical aging analysis of some common binders with the Fourier-Transform Infrared (FTIR) spectroscopy in the first phase of this project, the PAV simulates approximately 1 year of field exposure for a surface treatment (*1*). This 1 year of field exposure concurred with the 1 year performance monitoring period considered in this project. However, field validation with additional materials is needed to verify the use of the PAV, especially with modified binders.

Also, other test methods such as the Direct Tension Test (DTT) in terms of strain at failure (ε_f) can be explored in comparison or as a supplement to the BBR test results (7,8,*45*). Equally to be explored are other binder material characteristic properties in comparison or as a supplement to the G^* and/or S property for SPG grading of the binders.

SPG THRESHOLD VALUES

The final proposed SPG threshold values include a $G^*/Sin\ \delta$ value of 0.65 kPa for the higher temperature limit and an S value of 500 MPa and an *m-value* of 0.24 for the lower temperature limit (Appendix A). For each HS, researchers plotted these properties as a function of the binder type and the environmental temperature as shown in Figures 30, 31, and 32.

G*/Sin δ (kPa)

Whereas most of the binders had *G*/Sin δ* values greater than 0.65 kPa, the majority of the AC5-2% latex materials exhibited values around 0.20 kPa with a mean of 0.28 kPa (Figure 30). In fact, 86 percent of the AC5-2% latex binders failed the SPG specification in terms of the *G*/Sin δ* (kPa) limit. It is clear from Figure 30 that the AC5-2% latex material is the outlier. This means that the 0.65 kPa *G*/Sin δ* limit could possibly be too high for the AC5-2% latex material. This needs further investigation. Within the AC5-2% latex group, there was only one *G*/Sin δ* value of 0.76 kPa (HS45), which suggests either exceptionally good material or a discrepancy during laboratory testing. Like most of the AC5-2% latex HSs, HS45 exhibited adequate performance in the field (Appendices J, K, and L).

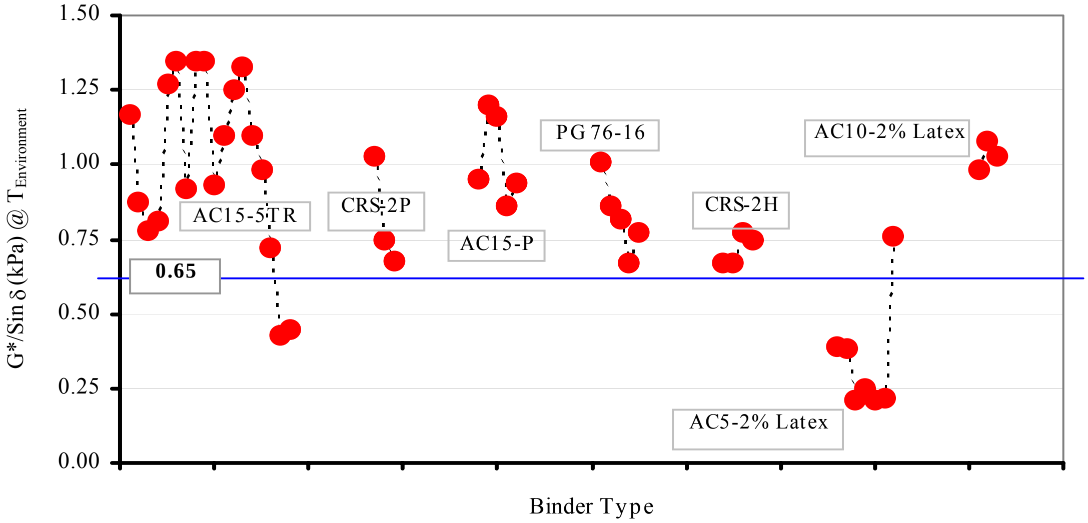


Figure 30. G*/Sin δ at Environmental Temperatures.

As evident in Figure 30, two of the AC15-5TR binder samples (HS39 and HS40) also had *G*/Sin δ* values less than 0.65 kPa, but these also performed inadequately (SCI score less than 70 percent) in the field (Appendices K and L), which concurs with the SPG specification.

Figure 31 is a summary of the mean *G*/Sin δ* values calculated for the respective binders used in the project.

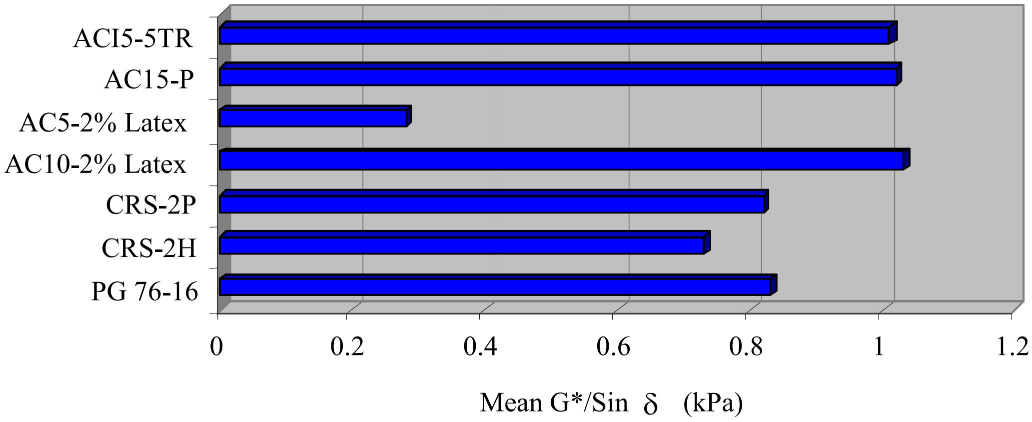


Figure 31. Mean G*/Sin δ Values per Binder Type.

It is clear from Figure 31 that the mean *G*/Sin δ* value for the AC5-2% latex material is the lowest (0.28 kPa) of all the binders. AC10-2% latex has the highest mean *G*/Sin δ* value (1.03 kPa), followed by AC15-P, AC15-5TR, PG 76-16, CRS-2P, and CRS-2H. However, these *G*/Sin δ* values may not directly relate to performance, which as previously stated is a function of many other influencing factors.

Flexural Creep Stiffness and *m-value*

Figure 32 is a plot of the binder flexural stiffness on the left and *m-value* on the right vertical axis against the respective HSs. As evident in Figure 32, all the binder samples tested met the SPG specification with flexural stiffnesses within the specified 500 MPa limit.

On the lower temperature limit, seven binder samples did not meet the SPG threshold value of an *m-value* of 0.24 (Figure 32). Two were AC5-2% latex samples (HS34 and HS35); one was a PG 76-16 (HS27); and four were AC15-5TR (HS2, HS13, HS39, and HS40). As mentioned previously, failure of this PG 76-16 (HS27, *m-value* = 0.21) was possibly due to a poor binder sample and the 3 ^{o}C grade increment. For HS13 (*m-value* = 0.20), inadequate performance was also recorded in the field in terms of aggregate loss (SCI_{AL} = 50 percent) in the winter when the pavement service temperature was relatively low (Appendices J, K, and L). This concurs with the SPG specification.

Similar to HS13; HS2, HS39, and HS40 equally exhibited inadequate performance (SCI < 70 percent) in the field (Appendices J, K, and L). Results for the AC5-2% latex materials remain inconclusive.

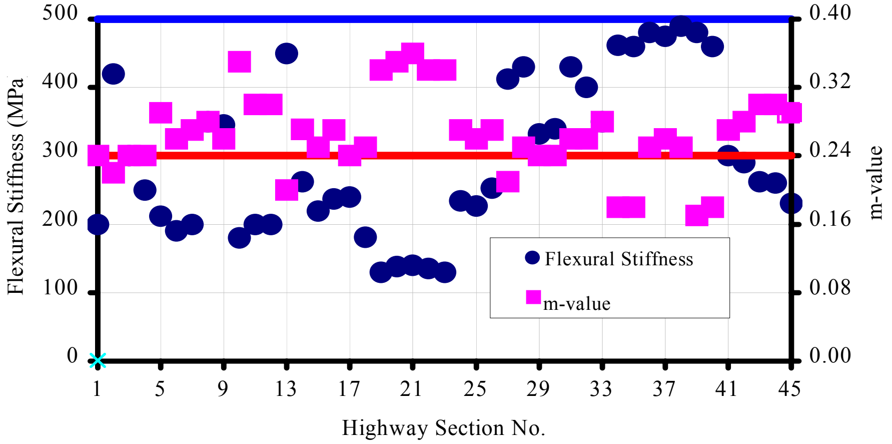


Figure 32. Binder Flexural Stiffness and *m-value* versus HS.

SPG GRADING CRITERIA

The effect of the 3 °C grade increment was discussed in Chapter 4 for HS27, as an example. Essentially, the binder fails to meet the specification primarily because the sequence of SPG grading follows a 3 °C (or 6 °C) increment and consequently some intermediate temperature values are excluded, e.g., moving from 61 to 64or -10 to -16. Researchers believe that this effect is likely to occur with any temperature grade increment used, but this is necessary to preclude an extraordinarily large number of required SPG grades.

Based on this observation, it is important that this effect be taken into account when testing and grading the binders. Failure to meet the SPG specification could be due to the temperature grade increment and not necessarily the binder itself. This will give an incorrect SPG grade and erroneous performance prediction for the binder.

On the other hand, the grade increment together with the rounding up of temperature values actually introduces the desired conservatism into the binder selection process. The net result is that a significant factor of safety is included in the binder selection scheme. An example is illustrated in Appendix B.

PERFORMANCE MONITORING AND EVALUATION CRITERIA

With respect to performance monitoring and evaluation of the HSs, researchers considered the following factors to have an effect on the field results: visual surveys, distress measurements, SCI analysis, and frequency of inspections.

Visual Surveys, Distress Measurements, and SCI Analysis

As discussed in Chapter 1, the visual survey technique was adopted for field performance monitoring because of its simplicity (considering the scope and time limitation of the project) and clear definition of the distress failure modes (aggregate loss and bleeding) in concurrence with the project objectives. However, it is a subjective method and is susceptible to giving inconsistent results, particularly if different evaluators are used (*24*). Thus, if not properly utilized, this method could negatively impact the overall results.

Researchers addressed these deficiencies by averaging the field results over two to four TSs per HS and using a ±5 percent tolerance in the SCI performance evaluation and rating analysis to account for any possible variations, inaccuracies, and errors in the distress measurements and calculations. Averaging field results over four TSs also minimized the possibility of erroneous results due to localized distresses or changes in surface elevation. Furthermore, having the same evaluators throughout the performance monitoring period and taking measurements and digital images from the same TS locations minimized inconsistencies in the results. Therefore, the visual survey technique as used in this project did not significantly impact either the failure of the HSs or the discrepancy between the SPG specification and field performance or exaggerate the distresses and/or performance of the HSs. Additionally, the digital images provided a supplementary visual reference of the HS performance and distresses.

The Performance Monitoring Survey Program and Frequency of Inspections

A 1-year performance monitoring survey program with three visual inspections (i.e., just after construction, after summer, and after winter) per TS per HS was conducted. Although this could have impacted the results of this validation project, the survey schedule and frequency of inspections were selected on the basis that surface treatment failures resulting from inappropriate materials, poor design, and/or construction often occur in their first year of service life. Often, most of these failures occur in summer and/or winter due to extreme temperatures, which have a significant effect on the binder viscosity (*12*). Also, a 1-year's performance monitoring period concurred with chemical aging analysis' findings that PAV simulates approximately 1 year of field exposure for a surface treatment (*7*).

With this in mind and considering the time limitation of the project, the performance monitoring survey program and frequency of inspections conducted were considered reasonable and acceptable. However, this does not discount the fact that with aging of the binder, increase in traffic, and changes in environmental conditions, the performance results for the surface treatments could be different in the later years of the service life.

DESIGN AND OTHER CONSIDERATIONS

Design factors that affect surface treatment performance include material application rates, traffic (in terms of ADT), material combination (including types and grades), and existing pavement conditions (*24,32,33,37,40,42,43,46,47,48,49*). The TxDOT procedure and general design considerations in relation to the findings of this project are discussed in the subsequent text.

TxDOT Design Procedures

The revised TxDOT Seal Coat and Surface Treatment Manual provides examples of binder and aggregate application rates from 1998 site-specific seal coat projects with different traffic levels and material types (*40*). The manual states that these typical quantities are only to be utilized as estimates for planning purposes with adjustments based on site-specific conditions and local experience. Actual material application rates are to be determined based on a design completed according to the Modified Kearby Method or the McLeod Method.

TxDOT most commonly uses the Modified Kearby Method (*13,33,40,46,47,48*). Required aggregate properties include bulk specific gravity, dry loose unit weight, and the aggregate quantity needed to cover 9.04 ft^2 of roadway found in the Board Test. This method includes correction factors for binder application rates for traffic level, existing surface condition, and embedment depth. Additional adjustments are required for emulsions to account for the evaporation of water and the time of year during construction (*32,33,40*).

In the McLeod Method, the aggregate application rate is determined as a function of aggregate gradation by means of the median particle size, aggregate shape measured by the flakiness index, dry loose unit weight, bulk specific gravity, and wastage (*33,37,40,48,49*). Correction factors for the binder application rate consider aggregate gradation, shape, and absorption; traffic level; existing surface condition; and residual asphalt content for emulsions (*33,37,40,48,49*).

General Design Considerations

Generally, the design binder application rate is a function of traffic and existing pavement conditions. For traffic, the higher the ADT, the lower the binder application rate and vice versa (*24,33,37,40,42*). For any given HS, this means that the binder application rate needs to be appropriately corrected and adjusted in the wheelpaths and on the outside slow lanes where traffic is often concentrated. Otherwise, bleeding is likely to occur. Examples in this project were HS11 and HS12, which had excessive bleeding in the wheelpaths of their outside lanes. No significant distress was observed in the inside lanes of either HS. On both HSs, the binder application rate was uniformly 0.30 gal/sy with no adjustments for traffic variation across the lanes or in the wheelpaths. Thus, design and construction appears to have been the cause of inadequate performance on these HSs. Although their SCI_{AL} and $SCI_{Overall}$ scores were greater than 70 percent, their SCI_{BL} scores were less than 70 percent ($SCI_{BL\ (HS11)}$ = 57 percent and $SCI_{BL\ (HS12)}$ = 58 percent) (Appendices J, K, and L). Similarly, the binder application rate on HS1 was not varied and this HS also performed poorly in terms of bleeding (SCI_{BL} = 50 percent).

For HS2, the binder application rate was appropriately varied in and between the wheelpaths to account for the differences in traffic intensity (0.42 gal/sy in the wheelpaths and 0.45 to 0.46 gal/sy between the wheelpaths). However, this binder application rate of 0.42 gal/sy was about 10.5 percent higher than the recommended 0.38 gal/sy for an ADT greater than 3000 and Gr3 aggregate (*33,40*). This appears to have contributed to the high bleeding of HS2 in the wheelpaths. Nonetheless, the AC15-5TR binder used on this HS also failed the SPG specification (Appendices I and J).

Failure to adjust and vary the binder application rate to account for the pavement conditions can lead to excessive aggregate loss or bleeding. A new smooth pavement with low air voids will not absorb much of the binder applied to it. Conversely, a dry, porous, and pocked pavement surface can absorb much of the applied binder. Other factors to consider when determining the binder application rate include the average least dimension (ALD), the desired percent aggregate embedment, and aggregate characteristics such as voids and absorption properties (*24,33,37,40,42*). The aggregate spread rate is, among others, a function of the aggregate dry loose unit weight, bulk specific gravity, voids, ALD, and traffic whip-off (*24,32,33,37,40,42,43,46,47,48,49*). The selected binder-aggregate combination for specific environmental locations is also a factor to be considered (*40*).

For any given ADT and material combination (binder and aggregate type and grade), optimum material design application or spread rates are paramount; otherwise, poor performance may surface in the field (*12,33,40*). Based on the scope of this project, researchers did not have control or influence over these design factors. It was assumed that design was adequate.

CONSTRUCTION AND QUALITY CONTROL PROCESSES

Although design and material selection can be satisfactory, construction still remains one of the key determinants of a surface treatment's success in terms of performance (*9,10,12*). Good workmanship and appropriate quality control methods play a significant role in ensuring good construction practices (*9*). Some of these construction practices are discussed in this section and provide illustrations of the possible effect of construction on surface treatment performance and its impact on this initial validation process of the SPG specification. Like design, construction was beyond the scope of this project and was assumed to be within specification.

General Weather Conditions

As part of good construction practices, a contractor must for example be wary of the weather conditions including the pavement surface temperature at the time of construction. It is unrealistic and unacceptable to place a surface treatment when it is raining or when the existing pavement temperature is very low, otherwise the binder will not hold (*9,10,12*). This can lead to traffic whip-off and aggregate loss. Based on data collected from the field, surface treatments on the selected HSs in this project were constructed when the pavement surface temperatures were well above 21 ^{o}C, in concurrence with the TxDOT recommendation (*5*). Therefore, this construction factor likely did not contribute to the poor performance of some of the HSs observed during field performance monitoring.

Environmental data in the vicinity of HS1 and HS39 indicated rainfall/snowfall on the order of about 0.08 and 0.51 in., respectively, at the time of construction (*50*). For HS39, relative humidity was also relatively high (approximately 78 percent) (*50*). These effects could have impacted the binder viscosity in terms of bonding to the existing pavement and holding the aggregate in place, resulting into aggregate loss evident on these HSs (e.g., $SCI_{AL\ (HS1)} = 76$ percent and $SCI_{AL\ (HS39)} = 52$ percent) (*8,9*).

Adherence to Design and Specifications

Although design can be adequate, construction may not be to specification. Actual material application rates and compaction in the field may not be consistent with design specifications or be consistently uniform. This can often lead to localized distresses as evident on the following HSs: HS1 (bleeding), HS2 (bleeding), HS11 (bleeding), HS15 (bleeding), HS27 (bleeding), HS39 (aggregate loss), and HS40 (aggregate loss) (Appendix L). On these HSs, there were localized distinct patches and areas of bleeding and aggregate loss, respectively. As described in the study by Wegman (*9*), good workmanship, good and effective quality control methods, and adherence to design and specifications are a key to good construction practices for a successful surface treatment.

Compaction and Aggregate Embedment

During surface treatment construction, optimum and proper compaction is essential to attain the desired level of aggregate embedment (*33*). Otherwise, excessive compaction resulting in excessive embedment can lead to bleeding and/or aggregate degradation. On the other hand, insufficient compaction can lead to traffic whip-off and aggregate loss due to inadequate embedment (*12,33*). This construction factor (compaction) could have therefore contributed to the bleeding and aggregate loss observed on some of the HSs in the project (e.g., HS1 and HS6) (Appendix L).

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

From the findings of this project, researchers have drawn the following conclusions and recommendations.

CONCLUSIONS

This project has shown that it is possible to initially validate and investigate the applicability of the proposed SPG specification through a comparison of the SPG binder grade predictions (based on laboratory testing) and actual field performance. With some exceptions, there was generally good agreement between the SPG binder grade predictions and actual field performance for 78 percent of the HSs. Considering that the HSs were randomly selected and the fact that the researchers did not have control over the design and construction of the surface treatments for the selected HSs, these results are credible. Thus, this project provides evidence that the proposed SPG specification is promising and motivation for further validation.

Overall, the results are indicative that the proposed SPG specification is functional and if properly applied, could be a relatively cost-effective method for selecting binders to ensure adequate surface treatment performance. The required laboratory tests utilize existing Superpave equipment and a stirred can emulsion recovery apparatus that can also be used for short-term aging of asphalt cements. Nonetheless, refinement of the specification is required to address some of the deficiencies and failures discussed.

On the basis of the results of this initial validation project, standardized SPG binder grades were established for five Texas environmental zones based on pavement surface temperatures, precipitation, and freeze/thaw conditions. These standardized SPG grades represent the binders used in the project with an assumed design reliability of 98 percent, and they are not exhaustive. Standardizing the binder grades also aids in streamlining the SPG products to the benefit of suppliers.

However, it should be emphasized that the practical (field) application of this SPG specification does not necessarily guarantee total satisfactory surface treatment performance. Design, aggregates, construction, and quality control also play a significant role toward ensuring adequate and satisfactory surface treatment performance; and these factors cannot be discounted.

RECOMMENDATIONS

Because of the limited scope of the project, this initial validation could not separate any effects on performance caused by faulty design, poor construction, or lack of quality control. These factors are critical to adequate performance, and, as Wegman (*9*) noted, even the best surface treatment materials cannot surmount poor construction practices to preclude failure. For further validation of the specification, the following recommendations are made:

- To focus solely on the effect of binder properties required by the SPG specification, controlled TSs must be carefully designed, constructed, and closely monitored. A research project of this nature is strongly suggested along with a synthesis of all recommended guidelines and specifications for adequate surface treatment performance. These performance specifications would address the critical aspects of design, construction, and quality control in addition to binder selection by the SPG specification and aggregate compatibility.
- Alternatively, a pilot implementation project can be conducted as one way to further validate the specification, including full monitoring of the design and construction parameters.
- In further validating the SPG specification, Estakhri's latest revised TxDOT Seal Coat and Surface Treatment Manual (*40*) along with other available guidelines and specifications could be an appropriate reference for the design and construction of the surface treatments for the controlled TSs and/or pilot implementation projects. The manual provides examples of material application rates from 1998 site-specific seal coat projects. Design procedures for both the Modified Kearby and the McLeod Methods are also provided.
- Other test methods such as the DTT can be explored for characterizing the binder low temperature properties in comparison or as a supplement to the BBR test results.
- Inconclusive results were obtained for the AC5-2% latex material. Researchers recommend that further testing and SPG grading be conducted on these materials and others not considered in the development and/or initial validation of the specification to establish SPG grades and possibly revised thresholds for these materials.
- Consistent with the scope of the project and binder PAV aging, performance monitoring was conducted only for a period of 1-year (the first year of service life), during which time

surface treatments with inappropriate materials or poorly designed and/or constructed are hypothesized to fail. For future validation, a performance monitoring period of more than a year can be conducted to capture the full effect of traffic, environmental conditions, and aging of the binder.

- Whereas traffic is usually accounted for during design in terms of determining the material application rates, it is not directly taken into account in the SPG specification. Future studies can explore the possibilities of directly incorporating this factor into the SPG binder grade selection process.

Lastly, it should be noted that the SPG specification is primarily concerned with binder selection and should thus be used concurrently with an additional specification for aggregates and the combined materials.

REFERENCES

1. Epps, A.L., Glover, J.C., and Barcena, R. *"A Performance-Graded Binder Specification for Surface Treatments".* Texas Transportation Institute. Research Report 1710-1, College Station, TX, October 2001.

2. Barcena, R., Epps, A., and Hazlet, D. "Performance-Graded Binder Specification for Surface Treatments". In *Transportation Research Record 1810*, TRB, National Research Council, Washington, D.C., 2002, pp. 63-71.

3. Shuler, S. "Chip Seals for High Traffic Pavements". In *Transportation Research Record 1259*, TRB, National Research Council, Washington, D.C., 1991, pp. 24-34.

4. Sigurjonsson, S., and Ruth, E.B. "Correlation between Field and Laboratory Performance of Liquid Asphalt-Based Seal Coats". In *Transportation Research Record 1259*, TRB, National Research Council, Washington, D.C., 1991, pp. 53-62.

5. *Standard Specifications for Construction of Highways, Streets and Bridges.* Texas Department of Transportation (TxDOT), Austin, TX, 1995.

6. American Society for Testing and Materials (ASTM). *Annual Book of ASTM Standards, Vol. 04.03: Road and Paving Materials.* American Society for Testing and Materials, Philadelphia, PA, 1998.

7. *Binder Specification and Testing*. Superpave Series SP-1. Asphalt Institute. Lexington, KY, 1997.

8. Roberts, F., Kandhal, P., Brown R., Lee, D., and Kennedy, T. *Hot Mix Asphalt Materials, Mixture Design, and Construction*. National Asphalt Pavement Association (NAPA) Education Foundation, Second Edition, Lanham, MD, 1996.

9. Wegman, D. *Design and Construction of Seal Coats.* Minnesota Department of Transportation, Mendota Heights, MN, 1991.

10. Kari, W., Coyne, L., and McCoy, P. "Seal Coat Performance-Interrelation of Variables Established by Laboratory and Field Studies". *Journal of The Association of Asphalt Paving Technologists*, Vol. 31, 1962, pp. 1-34.

11. Roque, R., Anderson, D., and Thompson, M. "Effect of Material, Design, and Construction Variables on Seal Coat Performance". In *Transportation Research Record 1300*, TRB, National Research Council, Washington, D.C., 1991, pp. 108-115.

12. Technical Recommendations for Highways (Draft TRH3). *Surfacing Seals for Rural and Urban Road,* Department of Transport, Pretoria, South Africa, 1998.

13. Epps, J.A., Gallaway, B.M., and Hughes, C.H. *Field Manual on Design and Construction of Seal Coats*. Texas Transportation Institute. Research Report 214-25, College Station, TX, 1981.

14. Elmore, W., Solaimanian, M., McGennis, R., Kennedy, T., and Phromsorn, C. *Performance-Based Seal Coat Asphalt Specifications*. Center for Transportation Research, CTR 1367-2F Final Report, Austin, TX, 1995.

15. Herrin, M. *State of the Art: Surface Treatment Summary. Summary of Existing Literature*. Special Report No. 96, Highway Research Board, National Research Council, Washington, D.C., 1968, pp.1-98.

16. McLeod, N. Do's and Don'ts of Seal Coating. *Presented at The American Road Builders Association. 11th Annual National Highway Conference for County Highway Engineers and Officials*, Gatlinburg, TN, September 15-18, 1963.

17. Shook, J., Shook, W., and Yapp, T. *The Effects of Emulsion Variability on Seal Coats*. Pennsylvania Department of Transportation. Report Number: FHWA-PA-89-030+86-12, 1990.

18. Kari, W., and Coyne, L. "Emulsified Asphalt Slurry Seal Coats". *Journal of The Association of Asphalt Paving Technologists*, Vol. 33, 1964, pp. 502-544.

19. Selim, A., and Heidari, N. *Measuring the Susceptibility of Emulsion Based Seal Coats to Debonding*, ASTM SPT 1016, American Society for Testing and Materials, Philadelphia, PA, 1989, pp. 144-153.

20. Stroup-Gardiner, M., Newcomb, D., Epps, J., and Paulsen, G. *Laboratory Test Methods and Field Correlations for Predicting the Performance of Chip Seals. Asphalt Emulsions*, ASTM STP 1079, American Society for Testing and Materials, Philadelphia, PA, 1990, pp. 2-19.

21. Burr, B.L., Davison, R.R., Glover, C.J., and Bullin, J.A. "Solvent Removal from Asphalt". In *Transportation Research Record 12969*, TRB, National Research Council, Washington, D.C., 1990, pp. 1-8.

22. Glover, C.J., Davidson, R., and Vassiliev, N.Y. "A New Method for Simulating Hot-Mix Plant Aging". Texas Transportation Institute. College Station, TX.

23. Takamura, K. "Comparison of Emulsion Residues Recovered by the Forced Airflow and RTFO Drying". *Paper presented at the Asphalt Emulsion Manufacturers Association (AEMA) meeting,* Charlotte, NC, 2000.

24. Roque, R., Thompson, M., and Anderson, D. "Bituminous Seal Coats: Design, Performance Measurements, and Performance Prediction". In *Transportation Research Record 1300*, TRB, National Research Council, Washington, D.C., 1991, pp. 90-97.

25. Strategic Highway Research Program (SHRP). *Distress Identification Manual for the Long-Term Pavement Performance Project.* Report No. SHRP-P-338, National Research Council, Washington, D.C., 1993.

26. Strategic Highway Research Program (SHRP). *Distress Identification Manual for the Long-Term Pavement Performance Studies.* Report No. SHRP-LTPP/FR-90-001, National Research Council, Washington, D.C., 1990.

27. Boyer, S., and Ksaibati, K. "Evaluating the Effectiveness of Polymer Modified Asphalts in Surface Treatments". Report Number: FHWA-WY-99/01F. Wyoming Department of Transportation, Cheyenne, WY, 1998.

28. Jackson, D., Jackson, N., and Mahoney, J. "Washington State Chip Seal Study". In *Transportation Research Record No. 1259*, TRB, National Research Council, Washington, D.C., 1990 pp.1-10.

29. *Pocket Facts*. Koch Materials Company – Koch Pavement Solution. (http://www.kochpavementsolutions.com/repair.htm) Accessed March 19th, 2003.

30. *Pocket Facts*. Asphalt Institute. (http://www.asphaltinstitute.org/faq/distresssummary.htm) Accessed March 19th, 2003.

31. Huang, Y.H. *Pavement Analysis and Design*. Prentice Hall, Englewood Cliffs, NJ, 1993.

32. Kearby, J.P. "Tests and Theories on Penetration Surfaces". *Proceedings,* Highway Research Board, Volume 32, 1953.

33. Gransberg, D.D., Senadheera, S., and Karaca, I. "Analysis of Statewide Seal Coat Constructibility". Texas Tech University, Project Report TX-98/0-1787-1R, Lubbock, TX, October 1998.

34. Montgomery, D.C., and Runger, G.C. *Applied Statistics and Probability for Engineers*. John Wiley & Sons, Inc. Third Edition, New York, NY, 2002.

35. Huber, G. "Weather Database for the Superpave Mix Design System". Report Number: SHRP-A-648A. Strategic Highway Research Program, National Research Council, Washington, D.C., 1993.

36. Huber, G.A. "Weather Database for the SUPERPAVE Mix Design System". Report SHRP-A-648A, Strategic Highway Research Program, National Research Council, Washington, D.C., February, 1994.

37. Janisch, D.W. "Reevaluation of Seal Coating Practices in Minnesota". In *Transportation Research Record No. 1507*, TRB, National Research Council, Washington, D.C., 1995, pp.30-38.

38. McDaniel, R.S. "Comparison of Conventional versus Modified Surface Seals with Three Aggregate Types". In *Transportation Research Record No. 1507*, TRB, National Research Council, Washington, D.C., 1995, pp. 23-29.

39. Kandal, P., and Motter, J. "Criteria for Accepting Precoated Aggregates for Seal Coats and Surface Treatments". In *Transportation Research Record 1300*, TRB, National Research Council, Washington, D.C., 1991, pp. 80-89.

40. Estakhri, C. *Revised TxDOT Seal Coat and Surface Treatment Manual.* Texas Transportation Institute. Unpublished Draft Report, College Station, TX, 2003.

41. Neville, A.M. *Properties of Concrete*. John Wiley & Sons, Inc., Fourth Edition, New York, NY, 1998.

42. Colwill, D.M., Mercer, J., and Nicholls, J.C. "U.K. Design Procedure for Surface Dressing". In *Transportation Research Record 1507*, TRB, National Research Council, Washington, D.C., 1995, pp. 13-22.

43. Benson, F.J., and Galloway, B.M. *Retention of Cover Stone by Asphalt Surface Treatments*. Bulletin 133, Texas Engineering Experiment Station, Texas A&M University System, College Station, 1953.

44. Freeman, T. *Flexible Pavement Database.* Texas Transportation Institute. Ongoing Research Project 187-06, College Station, TX, 2003.

45. *Pocket Facts*. (http://www.bohlin.co.uk/asphalt_test) Accessed March 30th , 2003.

46. Epps, J.A., Chaffin, C.W., and Hill, A.J. *Field Evaluation of a Seal Coat Design Method.* Texas Transportation Institute. Research Report 214-13, College Station, TX, 1980.

47. Epps, J.A., Galloway, B.M., and Brown, M.R. *Synthetic Aggregate Seal Coats*. Texas Transportation Institute. Research Report 83-F, College Station, TX, 1974.

48. McLeod, N.W. "Basic Principles for the Design and Construction of Seal Coats and Surface Treatments with Cutback Asphalt and Asphalt Cements". *Proceedings, Association of Asphalt Technologists*, Supplement to Vol. 29, 1960.

49. McLeod, N.W. "A General Method of Design for Seal Coats and Surface Treatments". *Proceedings, Association of Asphalt Technologists*, Vol. 38, 1969.

50. *Pocket Facts*. (AccuWeather.com) Accessed September 27, 2001 and August 23, 2002.

51. American Association of State Highway and Transportation Officials (AASHTO), *AASHTO Provisional Standards*, June Edition, 1998, Washington, D.C.: American Association of State Highway and Transportation Officials.

APPENDICES

APPENDIX A: THE FINAL PROPOSED SPG SPECIFICATION

Performance Grade	**SPG 58**				**SPG 61**				**SPG 64**			
	-10	**-16**	**-22**	**-28**	**-10**	**-16**	**-22**	**-28**	**-10**	**-16**	**-22**	**-28**
Average 7-day Maximum Surface Pavement Design Temperature, °C	<58				<61				<64			
Minimum Surface Pavement Design Temperature, °C	>-10	>-16	>-22	>-28	>-10	>-16	>-22	>-28	>-10	>-16	>-22	>-28
Original Binder												
Viscosity ASTM D 4402 (6) Maximum: 0.15 Pa·s*; Minimum: 0.10 Pa·s Test Temperature, °C	≤205				≤205				≤205			
Dynamic Shear, AASHTO TP315 (51) $\frac{G^*}{Sin\,\delta}$, Minimum: 0.65 kPa Test Temperature @10 rad/s, °C	58				61				64			
Pressure Aging Vessel (PAV) Residue (AASHTO PP1) (51)												
PAV Aging Temperature, °C	90				100				100			
Creep Stiffness, AASHTO TP313 (51) S, Maximum: 500 MPa m-value, Minimum: 0.240 Test Temperature @ 8s, °C	-10	-16	-22	-28	-10	-16	-22	-28	-10	-16	-22	-28

*Pa·s = Pascal-seconds

The above table presents only three SPG grades as an example, but the grades are unlimited and can be extended in both directions of the temperature spectrum using 3 and 6 °C increments for the high and low pavement temperatures, respectively.

APPENDIX B: DESIGN EXAMPLE OF THE SPG GRADE SELECTION PROCESS

An example is presented in Table B1 below to illustrate the SPG grade selection process. Assuming the available 35-year climatic data for a city registered -18 °C for the mean 1-day low temperature and 29 °C for the mean 7-day high temperature, with standard deviations of 2.5 °C and 1.64 °C, respectively. The city's latitude is assumed to be 25 degrees. Table B1 presents the calculations for the determination of the pavement surface temperatures and the 50 and 98 percent reliability final SPG binder grades. From statistical tables of standard normal distributions (μ=0 and σ^2=1), the standard normal deviate (z-value) for 50 and 98 percent reliability are 0.00 and 2.06, respectively. The information presented in Table B1 also shows the effect of the 3 ^{o}C increment rounding and the reliability level in the grade selection of a binder for a given project.

Table B1. SPG Binder Grade Calculations and Selection Criteria.

Reliability Level (%)	**Step 1:** **High Pavement Surface Temperature (°C)**	**Step 3:** **Low Pavement Surface Temperature (°C)**	**Step 5:** **High-Low Design Pavement Surface Temperatures (°C)**	**Step 6:** **Final SPG Binder Grade Selection** **(Use Appendix A)**
-	$T_{surf} - T_{air} = -0.00618\ lat^2 + 0.2289\ lat + 24.4$ $T_{surf} - T_{air} = -0.00618\ (25)^2 + 0.2289\ (25) + 24.4 = 26.64$ $T_{surf} = 33.98 + T_{air} = 26.64 + 29 = 55.64$	$T_{surf} = T_{air} = -18$	56-18	SPG 58-22
-	**Step 2:** **High Design Temperature (°C)**	**Step 4:** **Low Design Temperature (°C)**	-	-
50	$T_{pav} = T_{surf} + (z\ H\ S_{air}) = 55.64 + (0.00 * 1.64) = 55.64$	$T_{pav} = T_{air} - (z\ H\ S_{air})$ $= -18 - (0 * 2.5) = -18$	56-18	**SPG 58-22**
98	$T_{pav} = T_{surf} + (z\ H\ S_{air}) = 55.64 + (2.06 * 1.64) = 58.64$	$T_{pav} = T_{air} - (z\ H\ S_{air})$ $= -18 - (2.06 * 2.5) = -23.15$	59-24	**SPG 61-28**

APPENDIX C: LIST OF HIGHWAY SECTIONS AND OTHER DETAILS

#	HIGHWAY SECTION DETAILS				DISTRICT		BINDER		AGGREGATE				TRAFFIC		DATE OF CONSTRUCTION
	Designation	**Highway Name**	**Length (miles)**	**Location** W=West E=East (Temp °C)*	**Name (Code)**	**County**	**Type**	**Supplier**	**Type**	**Precoating**	**Gradation**	**Supplier**	**ADT****	**Speed (mph)**	
1	HS1	SH 6	12.00	E (66-16)	Bryan (17)	Brazos	B1	BS2	A2	P	Gr4	-	19,260	70	09/19/01
2	HS2	US 287	8.75	E (66-16)	Lufkin (11)	Trinity	B1	BS1	A1	P	Gr3	AS1	> 3000	70	09/11/01
3	HS3	FM 1617	1.50	E (66-16)	Lufkin (11)	Trinity	B1	BS1	A1	P	Gr4	AS1	< 3000	50	09/10/01
4	HS4	FM 2973	1.30	E (66-16)	Lufkin (11)	San Jacinto	B1	BS1	A1	P	Gr5	AS1	< 3000	50	09/25/01
5	HS5	SH 7	4.05	E (66-16)	Lufkin (11)	Houston	B5	BS3	A1	U	Gr4	AS1	2100	70	10/01/01
6	HS6	SH 42	12.50	E (66-17)	Tyler (10)	Gregg	B1	BS2	A1	P	Gr4	AS2	5500	45	09/08/01
7	HS7	SH 31	18.00	E (66-17)	Tyler (10)	Smith	B1	BS2	A1	P	Gr3	AS2	7400	70	09/13/01
8	HS8	US 87	7.00	E (65-12)	Yoakum (13)	DeWitt	B5	BS4	A2	P	Gr4	AS3	5100	70	10/30/01
9	HS9	FM 318	2.00	E (65-12)	Yoakum (13)	Lavaca	B5	BS4	A2	P	Gr4	AS3	450	50	04/17/02
10	HS10	US 83	17.73	E (66-08)	Pharr (21)	Zapata	B1	BS5	A3	P	Gr4	AS5	4800	> 50	04/15/02
11	HS11	US 281(a)	2.96	E (66-08)	Pharr (21)	Brooks	B1	BS5	A2	P	Gr4	AS4	9800	> 50	04/15/02
12	HS12	US 281(b)	8.00	E (66-08)	Pharr (21)	Brooks	B1	BS5	A2	P	Gr4	AS4	10,100	> 50	04/15/02
13	HS13	FM 2926	11.00	W (67-20)	Abilene (08)	Callahan	B1	BS2	A2	P	Gr3	-	< 3000	50	05/22/02
14	HS14	SH 29	9.67	W (66-16)	Austin (14)	Burnet	B1	BS5	A4	P	Gr4	-	5000	> 50	05/16/02
15	HS15	SH 281	7.00	W (66-16)	Austin (14)	Burnet	B1	BS5	A4	P	Gr4	AS5	> 000	> 50	05/21/02
16	HS16	RM 1431	9.02	W (66-16)	Austin (14)	Blanco	B1	BS5	A4	P	Gr4	AS5	> 000	< 50	05/21/02

Legend:

Binders		Aggregate		Precoating		Gradations	
B1	AC15-5TR	A1	Lightweight	P	Precoated	Gr3	Grade 3
B2	AC-15P	A2	Limestone	U	Uncoated	Gr4	Grade 4
B3	AC5-2% Latex	A3	Gravel			Gr5	Grade 5
B4	AC10-2% Latex	A4	Sandstone				
B5	CRS-2P						
B6	CRS-2H						
B7	PG 76-16						

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*Generalized average TxDOT district temperature range; **Average Daily Traffic (ADT)

APPENDIX C (continued)

#	HIGHWAY SECTION DETAILS				DISTRICT		BINDER		AGGREGATE				TRAFFIC		DATE OF CONSTRUCTION
	Designation	**Highway Name**	**Length (miles)**	**Location** W=West E=East (Temp °C)*	**Name (Code)**	**County**	**Type**	**Supplier**	**Type**	**Precoating**	**Gradation**	**Supplier**	**ADT****	**Speed (mph)**	
17	HS17	US 87	7.00	W (66-16)	Austin (14)	Mason	B1	BS5	A4	P	Gr4	AS5	> 3000	> 50	05/20/02
18	HS18	FM 3405	7.75	W (66-16)	Austin (14)	Williamson	B1	BS5	A4	P	Gr4	AS5	< 3000	> 50	05/20/02
19	HS19	SH 72	12.47	E (65-11)	Corpus (16) Christi	Karnes	B2	BS5	A2	P	Gr4	AS4	1900	> 50	04/29/02
20	HS20	BU 181 G	2.50	E (65-11)		Karnes	B2	BS5	A2	P	Gr4	AS4	3500	> 50	04/29/02
21	HS21	FM 627	7.57	E (65-11)	Corpus (16) Christi	Karnes	B2	BS5	A2	P	Gr3	AS4	130	> 50	04/12/02
22	HS22	FM 2442	8.40	E (65-11)		Goliad	B2	BS5	A2	P	Gr3	AS4	210	> 50	04/15/02
23	HS23	FM 1351	10.60	E (65-11)	Corpus (16) Christi	Goliad	B2	BS5	A2	P	Gr3	AS4	30	< 50	04/17/02
24	HS24	US 385	23.60	W (67-18)	El Paso (24)	Brewster	B7	BS6	A2	P	Gr3	AS6	331	> 50	04/23/02
25	HS25	US 67(a)	9.68	W (67-18)	El Paso (24)	Brewster	B7	BS6	A2	P	Gr3	AS6	1582	> 50	05/08/02
26	HS26	US 67(b)	10.00	W (67-18)	El Paso (24)	Brewster	B7	BS6	A2	P	Gr3	AS6	1582	> 50	05/15/02
27	HS27	SH 118	18.60	W (66-18)	El Paso (24)	Brewster	B7	BS6	A3	P	Gr3	AS6	2430	> 50	05/30/02
28	HS28	FM 192	25.2	W (66-18)	El Paso (24)	Hudspeth	B7	BS6	A2	P	Gr3	AS11	213	> 50	07/01/02
29	HS29	FM 1402	11.85	E (66-17)	Atlanta (19)	Titus	B6	BS8	A1	U	Gr4	AS1	3400	> 50	05/14/02
30	HS30	FM 1001	8.94	E (66-17)	Atlanta (19)	Titus	B6	BS8	A1	U	Gr4	AS1	1 450	> 50	05/17/02

Legend:

Binders		Aggregate		Precoating		Gradations	
B1	AC15-5TR	A1	Lightweight	P	Precoated	Gr3	Grade 3
B2	AC-15P	A2	Limestone	U	Uncoated	Gr4	Grade 4
B3	AC5-2% Latex	A3	Gravel			Gr5	Grade 5
B4	AC10-2% Latex	A4	Sandstone				
B5	CRS-2P						
B6	CRS-2H						
B7	PG 76-16						

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*Generalized average TxDOT district temperature range; **Average Daily Traffic (ADT)

APPENDIX C (continued)

#	HIGHWAY SECTION DETAILS				DISTRICT		BINDER		AGGREGATE				TRAFFIC		DATE OF CONSTRUCTION
	Designation	**Highway Name**	**Length (miles)**	**Location** W=West E=East (Temp °C)*	**Name (Code)**	**County**	**Type**	**Supplier**	**Type**	**Precoating**	**Gradation**	**Supplier**	**ADT****	**Speed (mp)**	
31	HS31	FM 114	5.35	E (66-17)	Atlanta (19)	Bowie	B6	BS8	A1	U	Gr4	AS1	450	> 50	04/22/02
32	HS32	FM 3384	4.54	E (66-17)	Atlanta (19)	Camp	B6	BS8	A1	U	Gr4	AS1	770	> 50	05/09/02
33	HS33	SH 8	2.93	E (66-17)	Atlanta (19)	Bowie	B1	BS1	A1	P	Gr4	AS1	17 600	> 50	06/27/02
34	HS34	FM 146(a)	7.30	W (65-23)	Lubbock (05)	Swisher	B3	BS9	A3	U	Gr4	AS7	260	70	07/16/02
35	HS35	FM 146(b)	7.30	W (65-23)	Lubbock (05)	Swisher	B3	BS9	A3	U	Gr4	AS7	260	70	07/17/02
36	HS36	FM 2646	5.70	W (65-23)	Lubbock (05)	Hockley	B4	BS9	A2	P	Gr4	AS8	340	70	07/08/02
37	HS37	SH 207	1.10	W (65-23)	Lubbock (05)	Garza	B4	BS9	A3	P	Gr4	- - -	300	70	07/76/02
38	HS38	FM 212	8.30	W (65-23)	Lubbock (05)	Lynn	B4	BS9	A3	P	Gr4	AS8	260	70	07/17/02
39	HS39	FM 2298	5.67	W (65–26)	Amarillo (04)	Deaf Smith	B1	BS2	A2	P	Gr3	AS9	< 3 000	70	07/23/02
40	HS40	SH 152	6.40	W (65-26)	Amarillo (04)	Gray	B1	BS2	A2	P	Gr4	AS10	< 3 000	70	06/10/02
41	HS41	SH 176 (a)	12.20	W (68-18)	Odessa (06)	Andrews	B3	BS10	A2	P	Gr3	- - -	2 400	70	07/31/02
42	HS42	SH 176 (b)	30.00	W (68-18)	Odessa (06)	Martin	B3	BS10	A2	P	Gr4	- - -	810	70	08/06/02
43	HS43	SH 302 (a)	3.00	W (68-18)	Odessa (06)	Ector	B3	BS10	A2	P	Gr3	- - -	2900	70	08/13/02
44	HS44	SH 302 (b)	18.00	W (68-18)	Odessa (06)	Winkler	B3	BS10	A2	P	Gr3	- - -	2 000	70	08/14/02
45	HS45	FM 1787	11.00	W (68-18)	Odessa (06)	Midland	B3	BS10	A2	P	Gr4	- - -	< 3 000	70	08/16/02

Legend:

Binders		Aggregate		Precoating		Gradations	
B1	AC15-5TR	A1	Lightweight	P	Precoated	Gr3	Grade 3
B2	AC-15P	A2	Limestone	U	Uncoated	Gr4	Grade 4
B3	AC5-2% Latex	A3	Gravel			Gr5	Grade 5
B4	AC10-2% Latex	A4	Sandstone				
B5	CRS-2P						
B6	CRS-2H						
B7	PG 76-16						

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*Generalized average TxDOT district temperature range; **Average Daily Traffic (ADT)

APPENDIX D: PROJECT/HIGHWAY INFORMATION SHEET

FIELD INFORMATION COLLECTION SHEET

Project 417102/3

Superpave Binder Testing for Surface Treatment Binders

BINDER SAMPLE DETAILS	**District/County:**
SAMPLE LABEL:	**Sample Date:**
Size/Weight of Sample: *(g)*	**Sample Status:**

HIGHWAY DETAILS

Name of Highway/Road:	**Length of Section (miles):**
Location:	**Area/Section/ mile Post:**
Direction:	**Traffic Level:**

CONTACT DETAILS

Name of Firm:	
Contact Person:	Tel:
	Email:

MATERIALS AND PAVEMENT DETAILS

Item		**Description**		
Seal Type (Single, Double or Triple)				
Binder	- Type:		Typical Design Application Rate (gal/sy):	
	- Application Rate (gal/sy):	*(in wheelpath)* *(in middle)*	Binder Application Temperature (°C):	
	- Breaking Time in case of Emulsions (min):		Pavement Temperature @ Time of Construction (°C):	
	- Source/Supplier:			
Aggregate	- Type:			
	- Size & Shape:			
	- Gradation:			
	- Application Rate (cy/sy):		Typical Design Application Rate (cy/sy):	
	- Source/Supplier:			
Existing Pavement Structure/ Condition	- Surface/Thickness (inches):			
	- Base/Subbase/Subgrade:			
Date of Construction:			Traffic Control:	
Rolling Compaction:				
Traffic Level (ADT):			Traffic Speed (mph):	

WEATHER DURING CONSTRUCTION

Weather: (Clear, Sunny, Cloudy, Rainy, Windy, Haze, etc)			Relative Humidity (%):		**Special Conditions/Comments:**
Air Temperature (°C)	- Highest:		Wind Direction and Speed (mph):		
	- Average:				
	- Lowest:				
Rainfall/Snowfall (inches):					

APPENDIX E: EXAMPLE OF PROJECT/HIGHWAY INFORMATION

FIELD INFORMATION COLLECTION SHEET

Project 417102/3

Superpave Binder Testing for Surface Treatment Binders

BINDER SAMPLE DETAILS		**District/County:**	*LUFKIN, Trinity*
SAMPLE LABEL:	*417102-02 (HS2)*	**Sample Date:**	*09/11/2001*
Size/Weight of Sample:	*1530 g*	**Sample Status:**	***Received (09/12/2001)***

HIGHWAY DETAILS			
Name of Highway/Road:	***US 287***	**Length of Section (km):**	*8.75*
Location:	*Groveton -From Victoria Street to Polk County line*	**Area/Section/ km Post:**	*8.75 miles eastwards*
Direction:	*Both lanes (eastbound and westbound)*	**Traffic Level:**	*Low*

CONTACT DETAILS			
Name of Firm:			***TxDOT - Lufkin District Office***
Contact Person: ***W D (Maintenance Manager)***		Tel:	***936-635 3372***
		Email:	***jdn@dot.state.tx.us***

MATERIALS AND PAVEMENT DETAILS

Item		**Description**		
Seal Type (Single, Double or Triple)		*Single Seal*		
Binder	- Type:	*AC15 - 5TR*	Typical Design Application Rate (gal/sy):	*0.38*
	- Application Rate (gal/sy):	*0.42 (in wheel path)* *~0.45-0.46 (in middle)*	Binder Application Temperature (°C):	*177*
	- Breaking Time (min)	*N/A*	Pavement Temperature @ Time of Construction (°C):	*27*
	- Source/Supplier:	*BS1*		
Aggregate	- Type:	*Lightweight precoated with Koch CSS-1h*		
	- Size & Shape:	*Angular*		
	- Gradation:	*Grade 3*		
	- Application Rate (cy/sy):	*1/98*	Typical Design Application Rate (cy/sy):	*1/100*
	- Source/Supplier:	AS1		
Existing Pavement Structure/ Condition	- Surface/Thickness (inches):	*Limestone chip seal with hot-mix patches*		
	- Base/Subbase/Subgrade:	*Relatively in good condition except slick areas in wheelpaths*		
Date of Construction:		*09/11/2001 (09.00AM - 04.00PM)*	Traffic Control: *Pilot car and flag men*	
Rolling Compaction:		*5-6 pneumatic-tired rollers*		
Traffic Level (ADT):		*2750 (low volume, < 3000)*	Traffic Speed (mph):	*70*

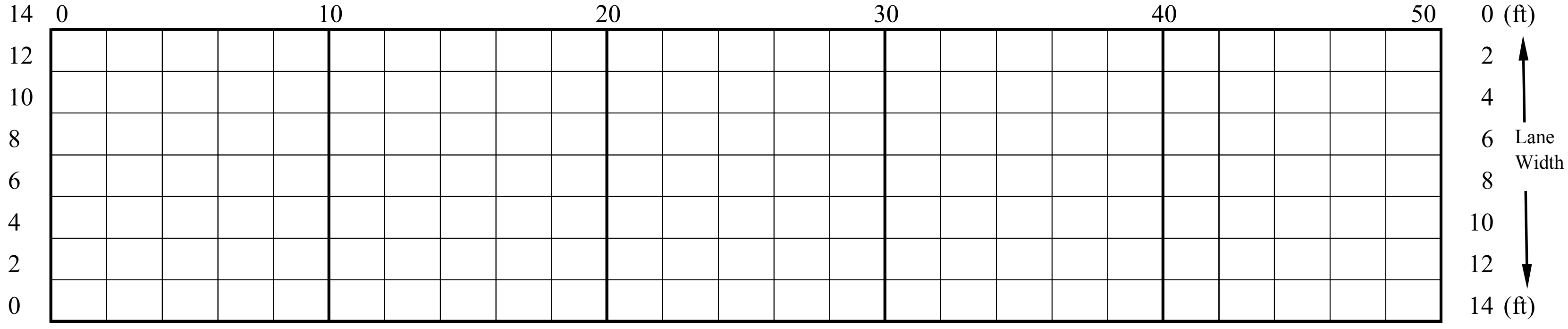
WEATHER DURING CONSTRUCTION

Weather: (Clear, Sunny, Cloudy, Rainy, Windy, Haze, etc)		*Sunny*	Relative Humidity (%):	*46.70*	**Special Conditions/Comments:**
Temperature (°C)	- Highest:	*28.90*	Wind Direction and Speed (mph):	*NNE* *8.00*	*1) Sample provided by Milton Liu from same tank as shipped to site.*
	- Average:	*28.30*			*2) Same sample/binder provided for FM 1617*
	- Lowest:	*27.20*			*3) Binder received on 09/12/01*
Rainfall/Snowfall (mm):		*0.06*			

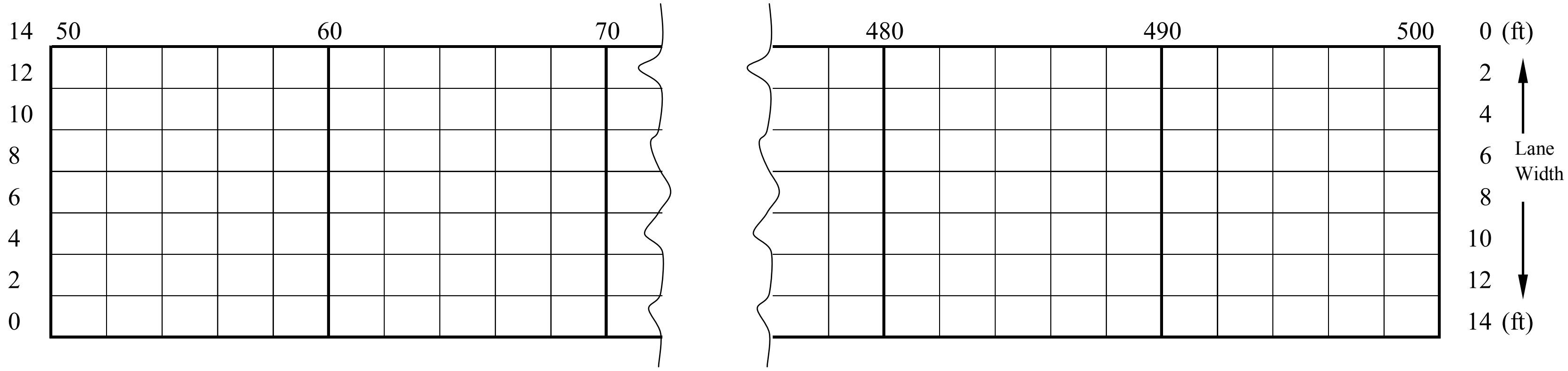
APPENDIX F: FIELD PERFORMANCE MONITORING SURVEY SHEET

VISUAL DISTRESS SURVEY SHEET

Hwy Section: ____________ Inspection No. ____________
Date: ____________ Time: ____________ Weather: ____________
Test Sction No. ____________ Start: ____________ End: ____________



Comment: ____



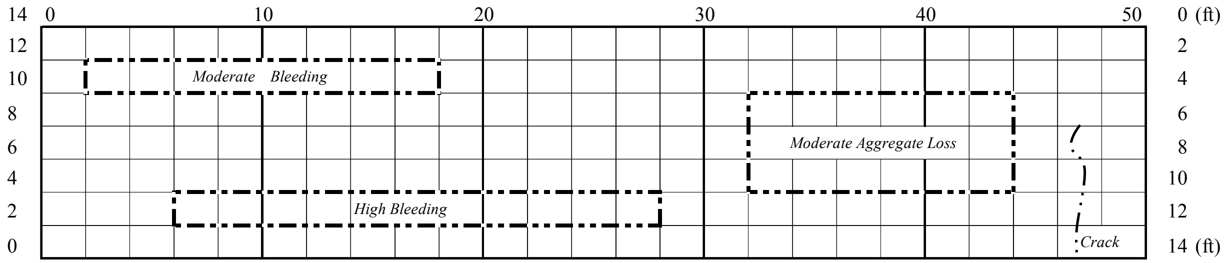
Comments: ____

Surveyed by: ____

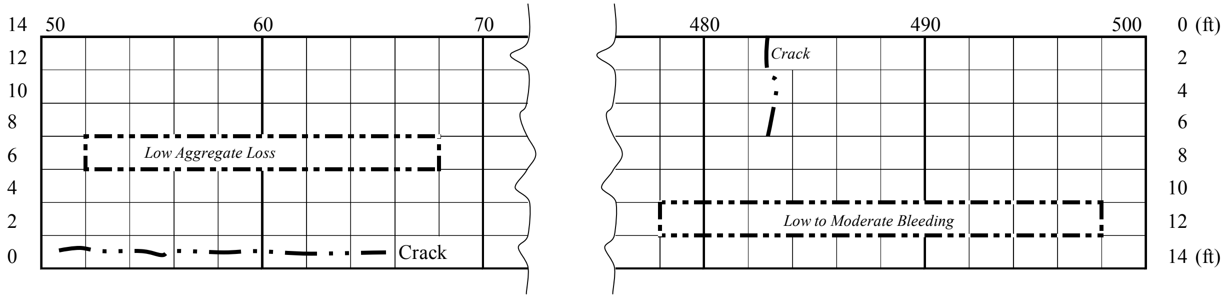
APPENDIX G: EXAMPLE OF FIELD PERFORMANCE MONITORING SURVEY

VISUAL DISTRESS SURVEY SHEET

Hwy Section: *HS1 (SH6)*
Inspection No. *3*
Date: *9/5/2002*
Time: *1.00PM*
Weather: *Sunny*
Test Sction No. 1
Start: *RM 588*
End: *RM 588 + 500 miles*



Comment: *Aggregate embedment = approximately 70% in wheel path, and about 30 to 40 % between wheel path*



Comment: *Evidence of localized bleeding. Prevalence of transverse cracks from underlying structure. Generally - inadequate performance (bleeding)*

Surveyed by: *LFW & BE*

Example of Distress Observations:

Consider for example, the following field survey observations on a particular highway section:

Aggregate Loss

Area coverage on 4 test sections:	***20%, 5%, 10%, and 3%***
Mean area coverage on 4 test sections:	***9.5%***
SCI score for distress area coverage (DAC):	***72%***
Severity levels for 4 test sections:	***Low to moderate, low to moderate, low, & low (Table 4)***
Percent severity on each test section is thus:	***10%10%, 5%, & 5% (see Figure 4)***
Mean percent severity:	***7.5%***
SCI score for degree of severity of aggregate loss (DSD):	***80%***

Cracking: ***Transverse cracking observed on some parts of the highway section***

Bleeding

Area coverage on 4 test sections:	***15%, 5%, 10%, & 10%***
Mean area coverage on 4 test sections:	***10%***
SCI score for distress area coverage (DAC):	***70%*** *(see Appendix H)*
Severity levels for 4 test sections:	***High, low, moderate to high, & moderate to high(Table 4)***
Percent severity on each test section is thus:	***95%, 5%, 50%, & 50% (see Figure 4)***
Mean percent severity:	***50%***
SCI score for degree of severity of bleeding (DSD):	***300%*** *(see Appendix H)*

Aggregate Embedment: ***60-90 % in wheel path***
30-50 % between wheel path

The SCI calculations and performance rating for this example are shown in Appendix H

APPENDIX H: EXAMPLE OF SCI CALCULATIONS AND PERFORMANCE RATING

DISTRESS EVALUATION SHEET

Highway/Road: *HS1 (SH 6)*
Location: *Brazos Valley*
Test Section No: *1, 2, 3, & 4*
Weather at Time of Inspection: *Sunny*
Inspection No: *3*
Date of Inspection: *9/5/2002*
Time of Inspection: *1.00 PM*
Season: *Fall (After Summer)*

Date of Construction:	*9/19/2001*	Season at Time of Construction:	*Fall*

No	Distress	Weight Calculations			SCI	Performance Rating/Comments
1	**AGGREGATE LOSS** Subdivision		Weighted sum (a+b)	Total Weight (0.80)	*61%*	Adequate, SCI_{AL} > 75±5%
	*(**a**) Area Coverage (DAC)* % area 100 50 [✓ 10] 0 SCI points 0 30 [✓ 72] 100	(a). Weight [0.5] 36	**SCI_{AL} =** ***76%***	60.8		
	*(**b**) Severity Level (DSD)* %severity 100 ***50*** 10 [✓ 7.5] 0 SCI points 0 ***30*** 70 [✓ 80] 100	(b). Weight [0.5] 40				
2	**BLEEDING** Subdivision		Weighted sum (a+b)	Total Weight (0.20)	*10%*	Inadequate (Poor), SCI_{BL} < 75±5%
	*(**a**) Area Coverage (DAC)* % area 100 50 [✓ 10] 0 SCI points 0 30 [✓ 70] 100	(a). Weight [0.5] 35	**SCI_{BL} =** ***50%***	10		
	*(**b**) Severity Level (DSD)* %severity 100 [✓ 50] 10 0 SCI points 0 [✓ 30] 70 100	(b). Weight [0.5] 15				
3	**LONGITUDINAL CRACKING** Subdivision		Weighted sum (a+b)	Total Weight (0.00)	*0%*	N/A
	*(**a**) Area Coverage (DAC)* % area 100 50 [✓ 10] 0 SCI points 0 30 [✓ 70] 100	(a). Weight [0.5] 35	**SCI_{LCr} =** ***70%***	0		
	*(**b**) Severity Level (DSD)* %severity 100 50 [✓ 10] 0 SCI points 0 30 [✓ 70] 100	(b). Weight [0.5] 35				
4	**TRANSVERSE CRACKING** Subdivision		Weighted sum (a+b)	Total Weight (0.00)	*0%*	N/A
	*(**a**) Area Coverage (DAC)* % area 100 50 [✓ 10] 0 SCI points 0 30 [✓ 70] 100	(a). Weight [0.5] 35	**SCI_{TCr} =** ***50%***	0		
	*(**b**) Severity Level (DSD)* %severity 100 [✓ 50] 10 0 SCI points 0 [✓ 30] 70 100	(b). Weight [0.5] 15				
	Overall Surface Condition Index ($SCI_{Overall}$)				***71%***	*Inadequate Performance,* *$SCI_{Overall}$ < 75±5%*
5	**AGGREGATE EMBEDMENT** *(a)* In wheelpath *(b)* Between wheelpath				***90%*** ***40%***	*Relatively High in Wheel Path*

APPENDIX I: SUMMARY OF SPG TEST RESULTS

#	HS	Binder		Environment		SPG Binder Grade	Remark****
		Type*	Supplier	Location**	Temperature Range (^{o}C) ***		
1	HS1	B1	BS2	E	66-16	SPG 70-16	Pass
2	HS2	B1	BS1	E	67-17	SPG 67-13	Fail @ T_L
3	HS3	B1	BS1	E	66-16	SPG 67-16	Pass
4	HS4	B1	BS1	E	66-16	SPG 67-16	Pass
5	HS5	B5	BS3	E	66-16	SPG 70-19	Pass
6	HS6	B1	BS2	E	65-15	SPG 70-19	Pass
7	HS7	B1	BS2	E	65-14	SPG 70-19	Pass
8	HS8	B5	BS4	E	66-13	SPG 67-16	Pass
9	HS9	B5	BS4	E	67-12	SPG 67-16	Pass
10	HS10	B1	BS5	E	66-08	SPG 67-19	Pass
11	HS11	B1	BS5	E	69-10	SPG 70-13	Pass
12	HS12	B1	BS5	E	69-10	SPG 70-13	Pass
13	HS13	B1	BS2	W	67-20	SPG 67-16	Fail @ T_L
14	HS14	B1	BS5	W	66-16	SPG 70-19	Pass
15	HS15	B1	BS5	W	66-16	SPG 70-19	Pass
16	HS16	B1	BS5	W	66-16	SPG 70-16	Pass
17	HS17	B1	BS5	W	66-16	SPG 70-16	Pass
18	HS18	B1	BS5	W	66-16	SPG 70-16	Pass
19	HS19	B2	BS5	E	65-11	SPG 67-16	Pass
20	HS20	B2	BS5	E	67-16	SPG 67-16	Pass
21	HS21	B2	BS5	E	65-11	SPG 67-16	Pass
22	HS22	B2	BS5	E	65-11	SPG 67-16	Pass
23	HS23	B2	BS5	E	65-11	SPG 67-16	Pass
24	HS24	B7	BS6	W	67-18	SPG 67-19	Pass
25	HS25	B7	BS6	W	67-18	SPG 67-19	Pass
26	HS26	B7	BS6	W	67-18	SPG 67-19	Pass
27	HS27	B7	BS6	W	66-18	SPG 67-16	Fail @ T_L

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*B1 = AC15-5TR, B2 = AC-15P, B3 = AC5-2% Latex , B4 = AC10-2% Latex, B5 = CRS-2P, B6 = CRS-2H, B7 = PG 76-16

**E = East, W = West

***Temperature range = obtained from weather station closest to HS

***T_H = higher temperature limit, T_L = lower temperature limit, $T_{H\&L}$ = higher and lower temperature limits

APPENDIX I (continued)

#	**HS**	**Binder**		**Environment**		**Binder SPG Grade**	**Remark******
		Type*	**Supplier**	**Location****	**Temperature Range (^{o}C)*****		
28	HS28	B7	BS6	W	67-18	SPG 67-19	Pass
29	HS29	B6	BS8	E	66-17	SPG 67-19	Pass
30	HS30	B6	BS8	E	66-17	SPG 67-19	Pass
31	HS31	B6	BS8	E	66-17	SPG 67-19	Pass
32	HS32	B6	BS8	E	66-17	SPG 67-19	Pass
33	HS33	B1	BS8	E	66-17	SPG 67-19	Pass
34	HS34	B3	BS9	W	65-23	SPG 58-16	Fail @ $T_{H\&L}$
35	HS35	B3	BS9	W	65-23	SPG 58-16	Fail @ $T_{H\&L}$
36	HS36	B4	BS9	W	67-24	SPG 67-25	Pass
37	HS37	B4	BS9	W	65-23	SPG 67-25	Pass
38	HS38	B4	BS9	W	66-21	SPG 67-25	Pass
39	HS39	B1	BS2	W	64-26	SPG 58-22	Fail @ $T_{H\&L}$
40	HS40	B1	BS2	W	66-24	SPG 61-22	Fail @ $T_{H\&L}$
41	HS41	B3	BS10	W	67-19	SPG 55-19	Fail @ T_H
42	HS42	B3	BS10	W	67-19	SPG 58-19	Fail @ T_H
43	HS43	B3	BS10	W	67-20	SPG 58-22	Fail @ T_H
44	HS44	B3	BS10	W	69-21	SPG 58-22	Fail @ T_H
45	HS45	B3	BS10	W	67-20	SPG 70-22	Pass

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*B1 = AC15-5TR, B2 = AC-15P, B3 = AC5-2% Latex , B4 = AC10-2% Latex, B5 = CRS-2P, B6 = CRS-2H, B7 = PG 76-16

**E = East, W = West

***Temperature range = obtained from weather station closest to HS

***T_H = higher temperature limit, T_L = lower temperature limit, $T_{H\&L}$ = higher and lower temperature limits

APPENDIX J: SUMMARY OF SPG-FIELD PERFORMANCE RESULTS

#	HS	SPG Specification*	Field Performance**	Match***
1	HS1	Pass	Fail	No
2	HS2	Fail	Fail	Yes
3	HS3	Pass	Pass	Yes
4	HS4	Pass	Pass	Yes
5	HS5	Pass	Pass	Yes
6	HS6	Pass	Pass	Yes
7	HS7	Pass	Fail	No
8	HS8	Pass	Pass	Yes
9	HS9	Pass	Pass	Yes
10	HS10	Pass	Pass	Yes
11	HS11	Pass	Fail	No
12	HS12	Pass	Fail	No
13	HS13	Fail	Fail	Yes
14	HS14	Pass	Pass	Yes
15	HS15	Pass	Pass	Yes
16	HS16	Pass	Pass	Yes
17	HS17	Pass	Pass	Yes
18	HS18	Pass	Pass	Yes
19	HS19	Pass	Pass	Yes
20	HS20	Pass	Pass	Yes
21	HS21	Pass	Pass	Yes
22	HS22	Pass	Pass	Yes
23	HS23	Pass	Pass	Yes

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*Pass = Binder meeting the environmental temperature demand @ 98 percent reliability in a given location in terms of the SPG threshold values,
Fail = Failure of a binder to meet the environmental temperature demand @ 98 percent reliability in a given location in terms of the SPG threshold values.
**Pass = Adequate performance of a highway section with SCI score ≥ 70 percent for both aggregate loss and bleeding,
Fail = Inadequate performance of a highway section with SCI score < 70 percent for either aggregate loss and/or bleeding.
***Yes = Good correlation or agreement between the SPG specification and field performance,
No = No correlation or disagreement between the SPG specification and field performance.

APPENDIX J (continued)

#	HS	SPG Specification*	Field Performance**	Match***
24	HS24	Pass	Pass	Yes
25	HS25	Pass	Pass	Yes
26	HS26	Pass	Pass	Yes
27	HS27	Fail	Pass	No
28	HS28	Pass	Pass	Yes
29	HS29	Pass	Pass	Yes
30	HS30	Pass	Pass	Yes
31	HS31	Pass	Pass	Yes
32	HS32	Pass	Pass	Yes
33	HS33	Pass	Pass	Yes
34	HS34	Fail	Pass	No
35	HS35	Fail	Pass	No
36	HS36	Pass	Pass	Yes
37	HS37	Pass	Pass	Yes
38	HS38	Pass	Pass	Yes
39	HS39	Fail	Fail	Yes
40	HS40	Fail	Fail	Yes
41	HS41	Fail	Pass	No
42	HS42	Fail	Pass	No
43	HS43	Fail	Pass	No
44	HS44	Fail	Pass	No
45	HS45	Pass	Pass	Yes

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*Pass = Binder meeting the environmental temperature demand @ 98 percent reliability in a given location in terms of the SPG threshold values,
Fail = Failure of a binder to meet the environmental temperature demand @ 98 percent reliability in a given location in terms of the SPG threshold values.
**Pass = Adequate performance of a highway section with SCI score ≥ 70 percent for both aggregate loss and bleeding,
Fail = Inadequate performance of a highway section with SCI score < 70 percent for either aggregate loss and/or bleeding.
***Yes = Good correlation or agreement between the SPG specification and field performance,
No = No correlation or disagreement between the SPG specification and field performance.

APPENDIX K: SCI GRAPHS AND DIGITAL IMAGES OF HIGHWAY SECTIONS

Examples of Adequate Performance: Pass (SPG) – Pass (Field Performance)

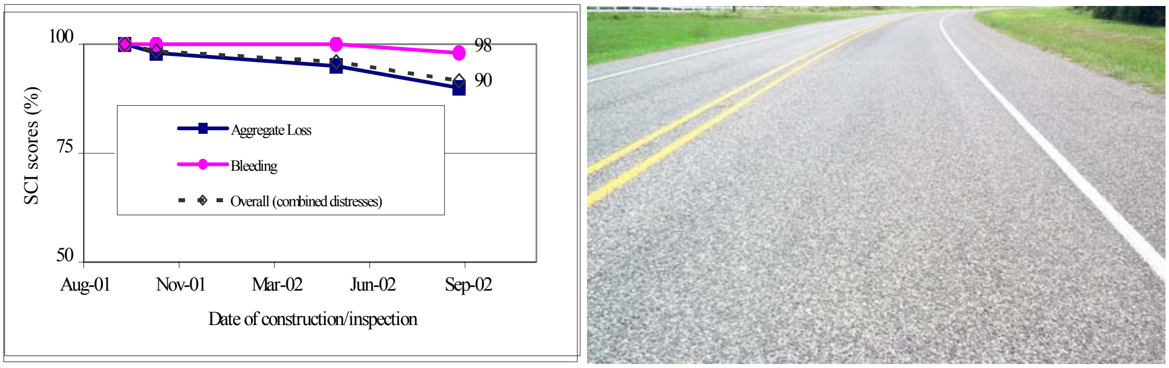

Figure K1. HS9, SCI ≥70% (CRS-2P, SPG 67-16, $T_{Environment}$ = 67-12 °C).

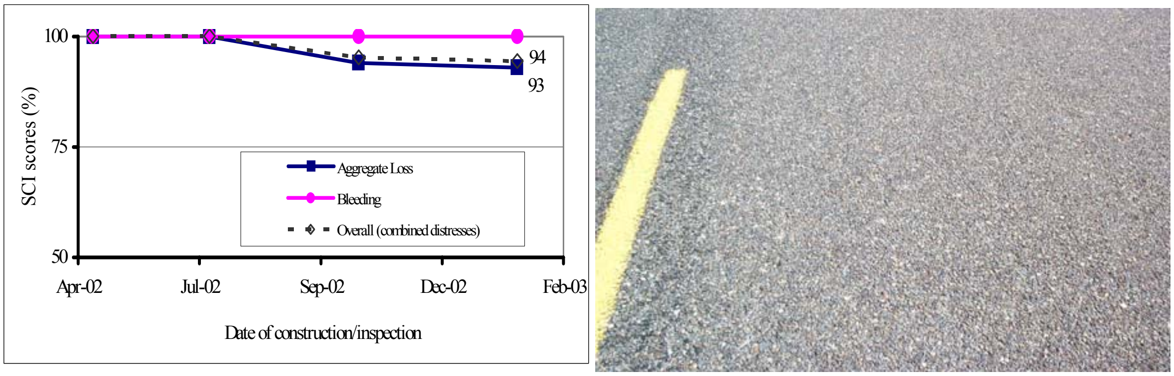

Figure K2. HS25, SCI ≥70% (PG 76-16, SPG 67-19, $T_{Environment}$ = 67-18 °C).

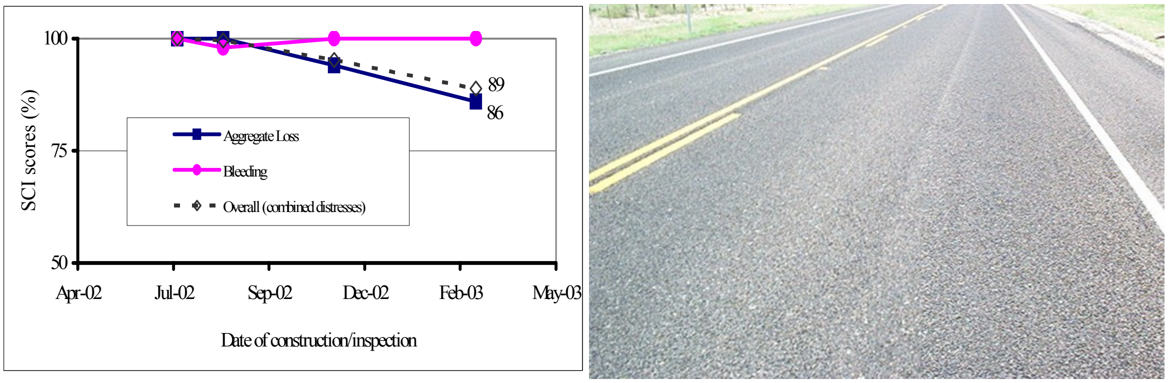

Figure K3. HS37, SCI ≥70% (AC10-2% Latex, SPG 67-25, $T_{Environment}$ = 65-23 °C).

APPENDIX K (continued)

Examples of Adequate Performance: Fail (SPG) – Pass (Field Performance)

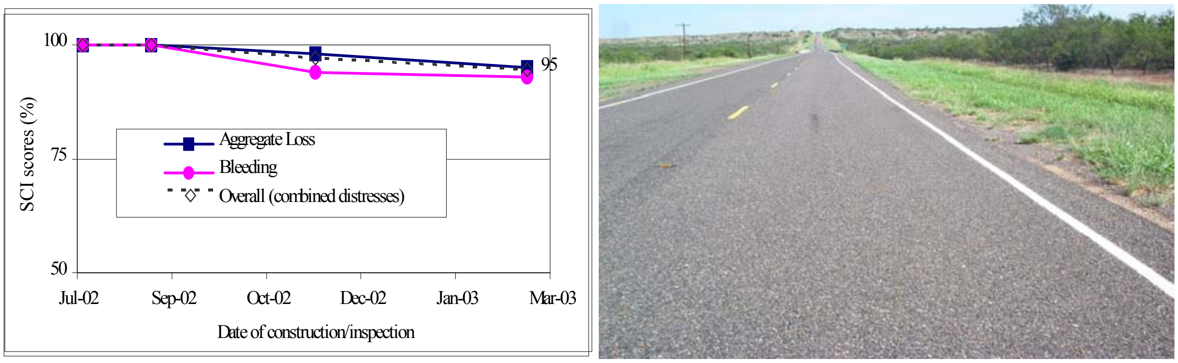

Figure K4. HS35, SCI ≥70% (AC5-2% Latex, SPG 58-16, $T_{Environment}$ = 65-23 ^{o}C).

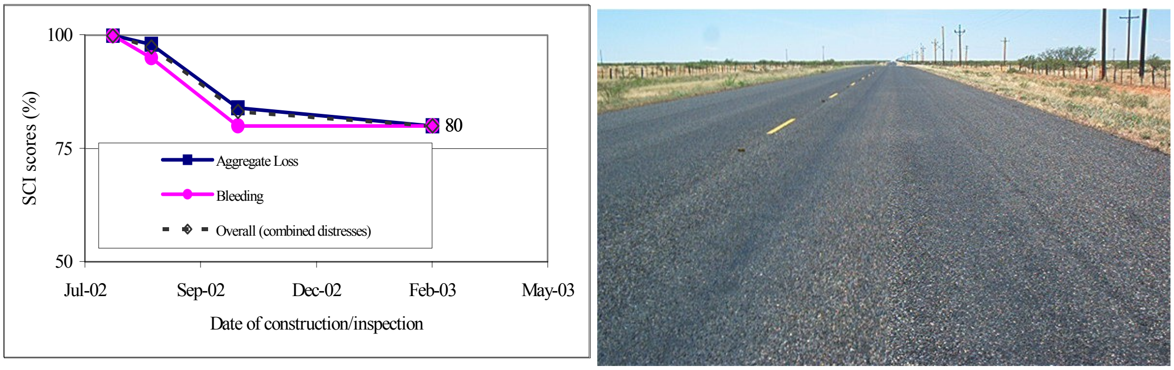

Figure K5. HS41, SCI ≥70% (AC5-2% Latex, SPG 55-19, $T_{Environment}$ = 67-19 ^{o}C).

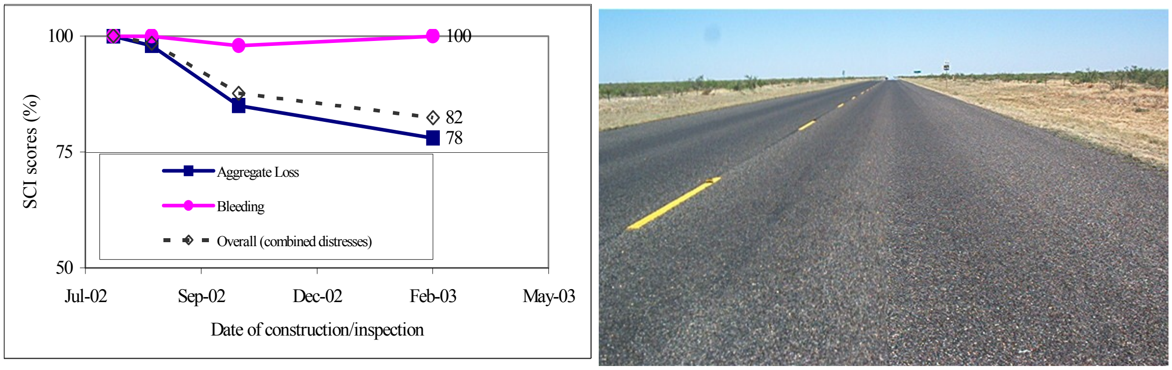

Figure K6. HS42, SCI ≥70% (AC5-2% Latex, SPG 58-19, $T_{Environment}$ = 67-19 ^{o}C).

APPENDIX K (continued)

Examples of Inadequate Performance: Pass (SPG) – Fail (Field Performance)

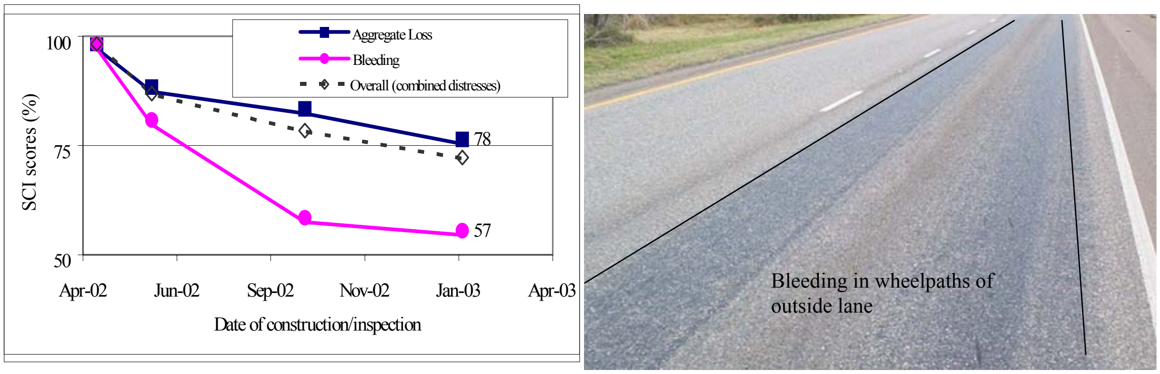

Figure K7. HS11, SCI_{BL} <70% (AC15-5TR, SPG 70-13, $T_{Environment}$ = 69-10 ^{o}C).

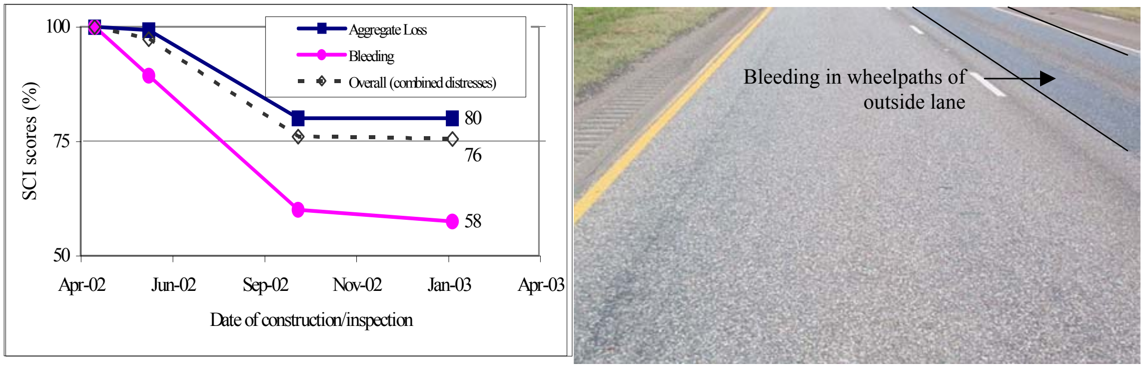

Figure K8. HS12, SCI_{BL} <70% (AC15-5TR, SPG 70-13, $T_{Environment}$ = 69-10 ^{o}C).

APPENDIX K (continued)

Examples of Inadequate Performance: Fail (SPG) – Fail (Field Performance)

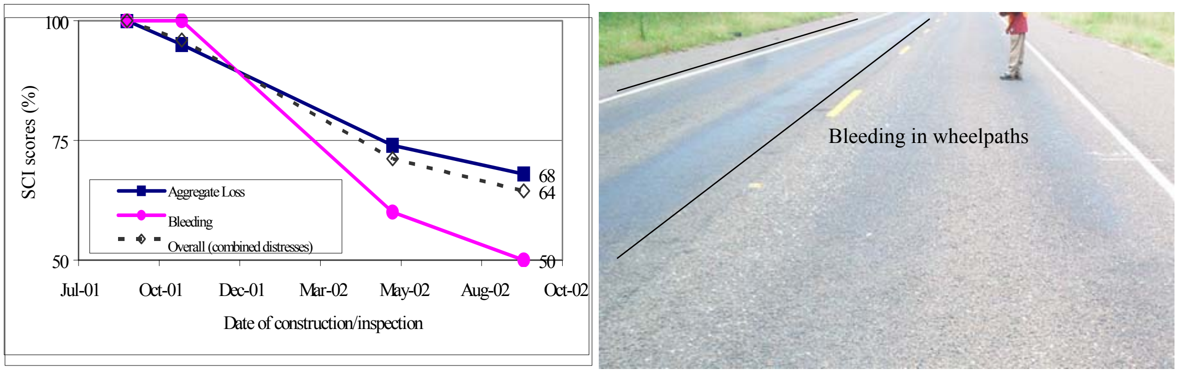

Figure K9. HS2, SCI$_{BL}$ <70% (AC15-5TR, SPG 67-13, T$_{Environment}$ = 67-17 °C).

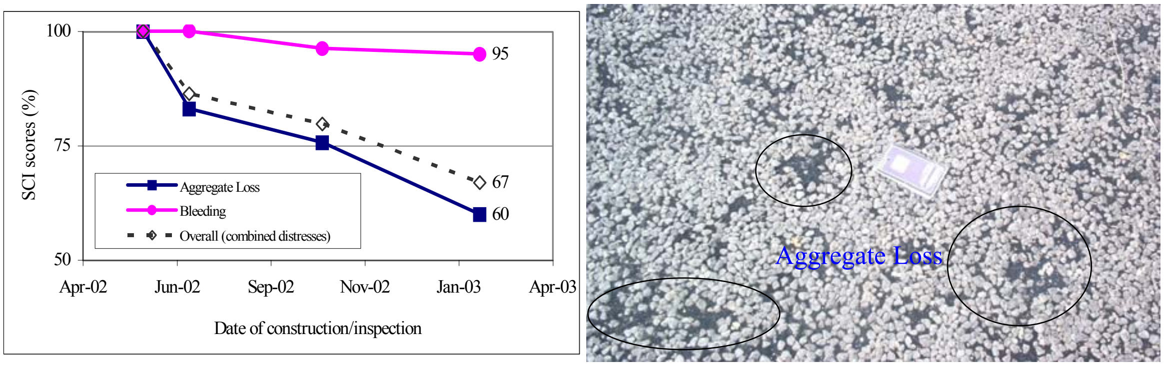

Figure K10. HS13, SCI$_{AL}$ <70% (AC15-5TR, SPG 67-16, T$_{Environment}$ = 67-20 °C).

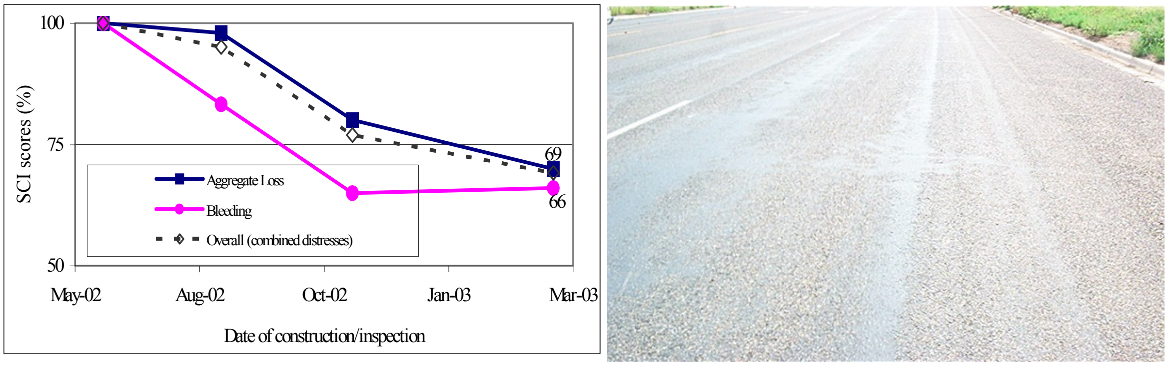

Figure K11. HS40, SCI <70% (AC15-5TR, SPG 61-22, T$_{Environment}$ = 66-24 °C).

APPENDIX L: ANALYSIS OF FAILURE AND DISCREPANCIES

HS	**Location**	**Binder**		**$T_{Environment}$ (°C)***	**Field Performance**		**General Design Data**	**Construction Data**	**Probable Causes of Failure/Discrepancy**
		Type	**SPG Grade**		**SCI** Score**	**Rating*****			
Pass (SPG) – Fail (Field Performance): (4 Hwy Sections, All AC15-5TR)									
HS1	Bryan	AC15-5TR	SPG 70-16	66-16	SCI_{AL}=76% SCI_{BL} = $\underline{50\%}$ $SCI_{Overall}$= 71%	Inadequate >*<u>Bleeding</u>* *(Summer)*	1. Recommended binder application rate for given ADT & Gr4 aggregate = 0.33-0.34 gal/sy for AC15-5TR 2. Recommended design aggregate application rate = 1/(117) – 1/(124) cy/sy for Gr4 precoated aggregates	1. Binder application rate = 0.35 gal/sy (no variation) 2. Aggregate application rate = 1/125 cy/sy 3. Pavement surface temperature @ construction = 50 °C 4. Existing pavement condition = single seal on HMAC with cracks 5. Compaction = 5 pneumatic tired rollers 6. Climatic conditions @ construction = sunny 7. Average air temperature @ construction = 27 °C 8. ADT = 19,260	1. High traffic – high ADT (19,260) as well as axle weight (trucks) and channelized traffic 2. High aggregate embedment in wheelpath (~90%) 3. Underlying structure – transverse & longitudinal cracks 4. Construction – localized bleeding
HS7	Tyler	AC15-5TR	SPG 70-19	66-17	SCI_{AL}= $\underline{60\%}$ SCI_{BL} = 76% $SCI_{Overall}$= 63%	Inadequate >*<u>Aggregate Loss</u>* *(Summer & Winter)*	1. Recommended binder application rate for given ADT & Gr4 aggregate = 0.36 (0.37-0.38) gal/sy for AC15-5TR 2. Recommended binder application rate for given ADT & Gr3 aggregate = 0.42 (0.43-0.44) gal/sy for AC15-5TR 3. Variation of binder application rates between wheelpaths & lanes = Yes 4. Recommended design aggregate application rate = 1/(115) cy/sy for Gr4 precoated lightweight 5. Recommended design aggregate application rate = 1/(95) cy/sy Gr3 precoated lightweight 6. Recommended pavement surface temperature @ construction = 21 °C	1. Binder application rate = 0.5 gal/sy 2. Binder temperature = 177 °C 3. Aggregate application rate = 1/90 cy/sy Gr3 precoated lightweight 4. Pavement surface temperature @ construction = 38 °C 5. Existing pavement condition = Dry 3 years old HMAC with cracks 6. Climatic conditions @ construction = Partly cloud 7. Average air temperature @ construction = 27 °C 8. ADT = 7400	1. Construction – Evidence of localized distresses. 2. High traffic volume (7400 ADT) & speed (70 mph). 3. Construction – Inadequate compaction

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*@ 98 percent reliability

**Surface Condition Index

***Adequate = SCI ≥70 percent, Inadequate = SCI < 70 percent

****Data not available

APPENDIX L (continued)

HS	**Location**	**Binder**		**$T_{Environment}$ (°C)***	**Field Performance**		**General Design Data**	**Construction Data**	**Probable Causes of Failure/Discrepancy**
		Type	**SPG Grade**		**SCI** Score**	**Rating*** **			
Pass (SPG) – Fail (Field Performance) (continued)									
HS11	Pharr	A15-5TR	SPG 70-13	69-10	SCI_{AL}=78% SCI_{BL} = $\underline{57\%}$ $SCI_{Overall}$ = 73%	Inadequate >*Bleeding* *(Summer)*	1. Recommended binder application rate for given ADT & aggregate = 0.30 gal/sy for AC15-5TR 2. Variation of binder application rates between wheelpaths & lanes (traffic) = None 3. Recommended design aggregate application rate = 1/(110-120) cy/sy for limestone or gravel 4. Construction aggregate spread rate = 1/(105-110) cy/sy for limestone or gravel 5. Recommended pavement surface temperature @ construction = 21 ºC	1. Binder application rate = 0.30 gal/sy through out (no variation for ADT) 2. Binder application temperature = 182 ºC 3. Aggregate application rate = 1/ 121 cy/sy Gr4 precoated limestone 4. Pavement surface temperature @ construction = 27 ºC 5. Average air temperature @ construction = 23 ºC 6. ADT = 9700	1. Design and construction - binder not varied accordingly for traffic in outside lane and wheelpaths (used 0.30 gal/sy through out) 2. High traffic volume & axle weights 3. High aggregate embedment in outside wheelpath (~90%) 4. Construction – localized bleeding 5. Inside lane was ok – no significant distress
HS12	Pharr	AC15-5TR	SPG 70-13	69-10	SCI_{AL}=80% SCI_{BL} = $\underline{58\%}$ $SCI_{Overall}$ = 76%	Inadequate >*Bleeding* *(Summer)*		1. Binder application rate = 0.30 gal/sy through out (no variation for ADT) 2. Binder application temperature = 204 ºC 3. Aggregate application rate = 1/121 cy/sy Gr4 precoated limestone 4. Pavement surface temperature @ construction = 27 ºC 5. Average air temperature @ construction = 25 ºC 6. ADT = 10,100	1. Design and construction - binder not varied accordingly for traffic in outside lane and wheelpaths (used 0.30 gal/sy through out) 2. High traffic volume & axle weights 3. High aggregate embedment in outside wheelpath (~90%) 4. Construction – localized bleeding 5. Inside lane is ok – no significant distress

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*@ 98 percent reliability
**Surface Condition Index
***Adequate = SCI ≥70 percent, Inadequate = SCI < 70 percent
****Data not available

APPENDIX L (continued)

HS	Location	Binder		$T_{Environment}$ (°C)*	Field Performance		General Design Data	Construction Data	Probable Causes of Failure/Discrepancy
		Type	SPG Grade		SCI** Score	Rating***			
Fail (SPG) – Pass (Field Performance): (6 Hwy Sections, All AC5-2% Latex)									
HS34	Lubbock	AC5-2% Latex	SPG 58-16	65-23	SCI_{AL}=85% SCI_{BL} = 80% $SCI_{Overall}$ = 84%	Adequate	1. Recommended binder application rate = 0.48 gal/sy 2. Binder application rate not based on ADT nor adjusted in wheelpath, but is varied depending on existing pavement conditions 3. Recommended aggregate spread rate is 1/(100) cy/sy 4. Aggregate spread rate adjusted for changes in surface texture or temperature conditions 5. Recommend ambient (air) temperature of T_{air} ≥ 16 °C at time of construction	1. Binder application rate = 0.46 gal/sy 2. Binder application temperature = 174 °C 3. Aggregate application rate = 1/(110) cy/sy	1. Results inconclusive 2. General comments: • More data is in Appendix C • Low ADT (< 3000) • More laboratory testing and SPG grading recommended
HS35			SPG 58-16	65-23	SCI_{AL}=94% SCI_{BL} = 97% $SCI_{Overall}$ = 95%	Adequate			

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*@ 98 percent reliability

**Surface Condition Index

***Adequate = SCI ≥70 percent, Inadequate = SCI < 70 percent

****Data not available

APPENDIX L (continued)

HS	**Location**	**Binder**		**$T_{Environment}$ (^{o}C)***	**Field Performance**		**General Design Data**	**Construction Data**	**Probable Causes of Failure/Discrepancy**
		Type	**SPG Grade**		**SCI** Score**	**Rating*****			
Fail (SPG) – Pass (Field Performance):(continued)									
HS41	Odessa	AC5-2% Latex	SPG 55-19	67-19	SCI_{AL} = 80% SCI_{BL} = 80% $SCI_{Overall}$ = 80%	Adequate	-****	-****	3. Results inconclusive 4. General comments: • More data is in Appendix C • Low ADT (< 3000) • More laboratory testing and SPG
HS42			SPG 58-19	67-19	SCI_{AL} = 78% SCI_{BL} = 100% $SCI_{Overall}$ = 82%	Adequate	-****	-****	
HS43			SPG 58-22	67-20	SCI_{AL} = 83% SCI_{BL} = 100% $SCI_{Overall}$ = 86%	Adequate	-****	-****	
HS44			SPG 58-22	67-10	SCI_{AL} = 85% SCI_{BL} = 90% $SCI_{Overall}$ = 86%	Adequate	-****	-****	

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*@ 98 percent reliability

**Surface Condition Index

***Adequate = SCI ≥70 percent, Inadequate = SCI < 70 percent

****Data not available

APPENDIX L (continued)

HS	Location	Binder		$T_{Environment}$ (ºC)*	Field Performance		General Design Data	Construction Data	Probable Causes of Failure/Discrepancy
		Type	SPG Grade		SCI** Score	Rating***			
Fail (SPG) – Fail (Field Performance): (4 Hwy Sections, All AC15-5TR)									
HS2	Lufkin	AC15-5TR	SPG 67-13	67-17	$SCI_{AL} = 68\%$ $SCI_{BL} = \underline{50\%}$ $SCI_{Overall} = 64\%$	Inadequate >*Aggregate loss* & *Bleeding* *(Summer & Winter)*	-****	1. Binder application rate = 0.42 gal/sy in wheelpath & 0.45 – 0.46 gal/sy between wheelpath 2. Binder application temperature = 177 ºC 3. Aggregate application rate = 1/(98) cy/sy Gr4 precoated lightweight 4. Pavement surface temperature @ construction = 27 ºC 5. Existing pavement condition = slick areas in wheelpath (lime chip seal with HMAC patches) 6. Compaction = 5 pneumatic tired rollers 7. Climatic conditions @ construction = Sunny 8. Average air temperature @ construction = 28.3 ºC 9. ADT > 3000	1. Binder failed SPG @ T_{Low} 2. High traffic – high aggregate embedment in wheelpath (70-90%) 3. Construction – evidence of localized patches of bleeding
HS13	Abilene	AC15-5TR	SPG 67-16	67-20	$SCI_{AL} = \underline{60\%}$ $SCI_{BL} = 95\%$ $SCI_{Overall} = 67\%$	Inadequate >*Aggregate loss* *(Winter)*	-****	1. Binder application rate = 0.44 gal/sy through out (no variation) 2. Binder application temperature = 177 ºC 3. Aggregate application rate = 1/(105) cy/sy Gr3 precoated limestone 4. Pavement surface temperature @ construction = 25.5 ºC 5. Existing pavement condition = Not in good condition 6. Compaction = 4 pneumatic tired rollers 7. Climatic conditions @ construction = Cloudy & Windy 8. Average air temperature @ construction = 24.9 ºC 9. ADT < 3000	1. Binder failed SPG specification @ T_{Low} 2. Inappropriate and poor binder material 3. Construction – low pavement surface temperature @ time of construction

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*@ 98 percent reliability

**Surface Condition Index

***Adequate = SCI ≥70 percent, Inadequate = SCI < 70 percent

****Data not available

APPENDIX L (continued)

HS	Location	Binder		$T_{Environment}$ (ºC)*	Field Performance		General Design Data	Construction Data	Probable Causes of Failure/Discrepancy
		Type	SPG Grade		SCI** Score	Rating***			
Fail (SPG) – Fail (Field Performance) (continued)									
HS39	Amarillo	AC15-5TR	SPG 58-22	64-26	SCI_{AL}= 52% SCI_{BL} = 63% $SCI_{Overall}$ = 54%	Inadequate >*Aggregate loss & Bleeding* *(Winter)*	1. Recommended binder application rate for given ADT & Gr3 aggregate = 0.37 – 0.88 gal/sy for AC15-5TR 2. Recommended binder application rate for given ADT & Gr4 aggregate = 0.23 – 0.63 gal/sy for AC15-5TR 3. Variation of binder application rates between Wheelpaths & lanes = Yes 4. Traffic = 70% outside and 30% inside lane 5. Recommended design aggregate application rate = 1/(110) cy/sy for Gr4 precoated limestone 6. Recommended design aggregate application rate = 1/(105) cy/sy for Gr3 precoated limestone 7. Recommended pavement surface temperature @ construction = 21 ºC	1. Binder application rate = 0.59 gal/sy 2. Binder application temperature = 177 ºC 3. Aggregate application rate = 1/(100) cy/sy Gr3 precoated limestone 4. Pavement surface temperature @ construction = 24.4 ºC 5. Compaction = 3 pneumatic rollers 6. Average air temperature @ construction = 32.8 ºC 7. ADT < 3 000	1. Binder failed SPG @ $T_{High \& Low}$ 2. Inappropriate and poor binder material 3. Inadequate aggregate 4. General comments: ▪ Bleeding possibly due to loss of aggregate
HS40			SPG 61-22	66-24	SCI_{AL}= 69% SCI_{BL} = 66% $SCI_{Overall}$ = 68%	Inadequate >*Bleeding* *(Summer & Winter)*		1. Binder application rate = 0.38 gal/sy 2. Binder application temperature = 177 ºC 3. Aggregate application rate = 1/(105) cy/sy Gr4 precoated limestone 4. Pavement surface temperature @ construction = 27.8 ºC 5. Compaction = 3 pneumatic rollers 6. Climatic conditions @ construction = Sunny 7. Average air temperature @ construction = 35.5 ºC 8. ADT < 3 000	1. Binder failed SPG @ $T_{High \& Low}$ 2. Inappropriate and poor binder material 3. Inadequate aggregate 4. General comments: ▪ Bleeding possibly due to loss of aggregate

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*@ 98 percent reliability
**Surface Condition Index
***Adequate = SCI ≥70 percent, Inadequate = SCI < 70 percent
****Data not available

APPENDIX M: STANDARDIZED SPG GRADES BY BINDER TYPE @ 98 PERCENT RELIABILITY

#	Binder	Standardized SPG Grades
1	AC15-5TR	SPG 64-16 SPG 67-16 SPG 67-22 SPG 70-10 SPG 70-16 SPG 70-22
2	AC15 –P	SPG 67-16 SPG 67-22 SPG 67-28
3	AC5	SPG 55-22 SPG 58-28
4	AC5-2% Latex	SPG 55-22 SPG 58-22 SPG 70-22
5	AC10	SPG 61-16
6	AC10-2% Latex	SPG 64-16 SPG 67-22 SPG 67-28
7	CRS-1P	SPG 52-22 SPG 58-22 SPG 58-28
8	CRS-2P	SPG 58-28 SPG 64-16 SPG 67-16 SPG 67-22 SPG 70-22 SPG 70-28
9	CRS-2H	SPG 67-16 SPG 67-22
10	PG 76-16	SPG 67-16 SPG 67-22
11	AC20	SPG 64-16
12	HFRS2	SPG 61-28
13	HFRS2-P	SPG 70-22

Note: The standardized SPG binder grades listed in the above table are not exhaustive.