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16. Abstract
Many government agencies have used surface treatments as part of their maintenance and rehabilitation programs to improve surface quality and extend the service life of pavements. Traditional specifications for asphalt binders failed to characterize materials across the entire spectrum of temperatures experienced during production and construction and in-service and required properties that were not directly related to performance. As part of the Strategic Highway Research Program (SHRP) previous researchers developed the Superior Performing Asphalt Pavements (Superpave) or performance-graded (PG) asphalt binder specification in the 1990s to measure binder properties directly related to hot mix asphalt concrete (HMAC) performance and included material characterization at low, intermediate, and high temperatures. Direct application of the PG binder specification to binders used in surface treatments is not appropriate due to differences between surface treatments and HMAC in terms of distress types, construction methods, and exposure to environmental conditions.

The objective of this study conducted for the Texas Department of Transportation was to develop a performance-based specification system for surface treatment binders that maximizes the use of existing equipment required in the PG system for HMAC binders. This new surface performance grading (SPG) specification assumes appropriate design and construction practices and considers only binder properties after construction. Researchers developed the SPG based on the identification of common distresses and analysis of physical properties of surface treatment binders measured at multiple temperatures and corresponding performance in specific environmental conditions. The final SPG includes suggested limiting values for high and low surface pavement design temperatures. Researchers recommend implementation of the new SPG after results from the suggested validation experiment are obtained.

17. Key Words
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DISCLAIMER

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CHAPTER 1. INTRODUCTION

All highway networks deteriorate with time, traffic, and environmental conditions. Eventually, pavements in this type of network require some type of maintenance or reconstruction procedure to improve surface quality and extend service life. Many government agencies have used surface treatments in this capacity as part of their maintenance and rehabilitation programs. These treatments are versatile, from a temporary riding surface when constructed on top of a base to a moderate maintenance job or a quick remedy before a major reconstruction project. When properly designed and constructed, surface treatments are practical, efficient, and economical solutions that improve the serviceability and ride quality.

Researchers and practitioners can employ the term surface treatment as a general designation for a treatment utilized to restore the surface quality and useful life of a pavement. Many pavement treatments including seal coats, fog seals, sand seals, slurry seals, and microsurfacing fall under this general classification. Although these types of treatments are very common, there is not a well-established consensus of the meaning of the term surface treatment. The Texas Department of Transportation (TxDOT) defines a surface treatment as a single, double, or triple application of asphaltic material, each covered with aggregate, constructed on existing pavement or on a prepared base course *(1)*. For this study, researchers used the term surface treatment throughout the report consistent with the TxDOT definition.

In the state of Texas $324 million was budgeted for routine maintenance in 2001 *(2)*. In past years, The Pennsylvania Department of Transportation (PennDOT) had contemplated in its maintenance program the application of seal coats to over 5000 miles (8047 km) of roadway *(3)*. In the state of Washington, approximately 50 percent of the highway system has some type of surface treatment *(4)*. With this extensive use of surface treatment applications, quality control through specifications is important to ensure adequate performance.

Historically, researchers and practitioners classified asphalt binders in many different ways. Two major classification methodologies based on penetration at 25 °C (American Society for Testing and Materials (ASTM) D 946) and viscosity at 60 °C (ASTM D 3381) have been commonly used to specify asphalt binders for many different applications, including hot-mix asphalt concrete (HMAC) and surface treatments *(5)*.

Asphalt binders are classified as viscoelastic materials, that is, their physical behavior has both elastic and viscous components. Physical response of these materials is also dependent on temperature and rate of loading. Penetration and viscosity classification systems were state-of-the-art at their inception, but these systems have presented numerous deficiencies due to the fact that they fail to characterize binders across the entire spectrum of temperatures experienced during production, construction, and in-service temperature ranges. These systems are primarily based on consistency and do not take into account long-term aging of the binders. In addition, these measurements do not fully explain viscoelastic behavior or temperature susceptibility, and required properties are not directly related to performance.

In 1987, the Congress of the United States of America established the Strategic Highway Research Program (SHRP) as a research program to improve the overall performance of roads in the U.S. One of the results of this endeavor was the development of a performance-based asphalt binder specification that relates laboratory analysis to field performance *(6)*. SHRP researchers called this new classification method the Superior Performing Asphalt Pavements (Superpave) or performance-graded (PG) binder specification. The Superpave PG specification included low-, intermediate-, and high-temperature characterization of binders.

The SHRP Superpave specification accomplished many important advances. This system included use of the Pressure Aging Vessel (PAV) to simulate long-term aging of the binder in the field. Secondly, SHRP researchers developed new testing equipment to measure binder properties directly related to performance in terms of resistance to the three primary forms of distress in HMAC: rutting, fatigue cracking, and thermal cracking. Finally, the new specification allowed for the possibility of selecting a level of reliability in the binder selection processes. The industry regarded these three advances as substantial progress in asphalt binder characterization, and researchers in this study recognized that this progress should be included in future specifications.

SHRP researchers developed the Superpave classification system based on pavement behavior and intended for HMAC design and material selection. Consequently, direct application of this binder classification to other purposes, such as characterization of binders used in surface treatments, would not be appropriate due to differences between surface treatments and HMAC in terms of distress types, construction methods, and exposure to environmental conditions. The main objective of this research project is to develop a performance-based specification system and an associated grade selection process for surface treatment binders that considers these differences and maximizes the use of existing equipment required in the Superpave PG specification system. This new surface performance grading (SPG) specification assumes appropriate design and construction practices and considers only binder properties after construction.

To develop the SPG specification, researchers completed three major tasks. First, they identified commonly used materials and properties related to distresses in surface treatments other than those in the existing PG system through an information search. Secondly, they designed a comprehensive experiment based on the collected information and completed an extensive laboratory testing program. The third and final task they completed included analysis of testing results and development of the proposed SPG specification and associated grade selection process. They also proposed a field validation experiment. This report describes each task in subsequent sections followed by conclusions and recommendations.

CHAPTER 2. INFORMATION SEARCH

The information search included a literature review and an evaluation survey of the TxDOT districts.

LITERATURE REVIEW

Previous researchers conducted a number of studies to illustrate primary purposes, benefits, and uses of surface treatments. Other research projects focused on common distresses, design procedures, materials, and desired properties of binders used in surface treatments. This section summarizes information included in these documents.

Purpose and Benefits

According to the literature, surface treatments are placed on existing pavements to *(7,8)*:

- seal the existing bituminous surface against the entrance of water and air,
- enrich an existing dry or raveled surface,
- provide a skid-resistant surface,
- increase pavement visibility at night,
- reduce tire noise,
- improve demarcation of traffic lanes or other geometric features,
- attain a uniform appearing surface, and
- reduce the brittleness of the underlying layer of bituminous material.

These conditions may be related to bleeding; longitudinal, transverse, and block cracking; worn aggregate; or lack of uniformity of the existing surface.

Besides maintenance purposes, surface treatments are commonly used on pavement bases as provisional riding surfaces or protective seals against intrusion of water or other deleterious substances until placement of a permanent HMAC layer. Surface treatments are also frequently used before overlays as part of the rehabilitation process.

Distress

The most frequently observed distresses in surface treatments are as follows *(4, 9)*:

- aggregate loss,
- flushing,
- windshield damage,
- excessive aggregate use, and
- streaking.

Researchers and practitioners normally attribute these distresses to improper construction practices, design, materials, or misjudgment in the use of a surface treatment when another corrective measure should have been applied.

Design

Researchers found several design methods in the literature *(7, 9, 10, 11)*. Although different procedures are employed in each method, they utilize some of the same factors. Common variables included in each procedure are presented in Table 1.

Table 1. Variables Included in Design Methodologies.

Design Method	Variables Considered	
Kearby	• Embedment • Dry unit weight of aggregate • Board test result	• Traffic • Surface condition • Weather correction
McLeod	• Loose unit weight of aggregate • Voids in cover aggregate • Flakiness index	• Mean aggregate size • Average least dimension
Minnesota DOT	• Average particle diameter (Spread modulus)	
Pennsylvania DOT	• Condition of existing pavement • Spread modulus of the aggregate	• Absorption capacity of the aggregate • Average daily traffic
Voids Percentage	• Bulk specific gravity • Average least dimension • Void reduction	• Skid resistance • Volatile factors

Aggregates

Several types of aggregates may be used in surface treatments. These include crushed limestone, river rock, granite, lightweight aggregate, and scoria. Normally they should be uniform in size with an average chip size under 0.5 in (12.7 mm). The aggregate should be clean and with a minimal amount of fines. The stones should be able to withstand crushing, abrasion, and wearing by traffic *(12)*.

The literature includes numerous tests to evaluate and select aggregates to assure quality surface treatments. Pennsylvania DOT recommends performing the following tests on aggregate: sieve analysis, hydrometer analysis (percent finer than given size expressed as percent of total aggregate), flakiness index, Los Angeles abrasion test, crush count (percent crushed faces), bulk specific gravity, and absorption *(13)*. Additionally, other international agencies have proposed polishing, soundness, wearing, fragmentation, freeze-thaw, and a boiling test to evaluate adequacy of aggregates *(14)*.

Binders

A variety of asphalt cements and asphalt emulsions are currently used as binding materials in surface treatments. The application of cutback materials has been discontinued because of environmental issues. Generally, asphalt cements used in surface treatments tend to be softer than the asphalts used in HMAC because they have to be sprayed. Many of these asphalt cements normally used for this type of application contain some kind of modifier to enhance high-temperature stiffness and ensure adequate performance. Emulsions are more practical in the sense that they do not have to be heated as much to be sprayed, but users must consider breaking and setting times.

The basis for binder selection in the design process is not well defined. Some agencies always use the same type of binder without accounting for special conditions and circumstances of each project. For example, Pennsylvania DOT specifications permit only the use of RS-2 and CRS-2 emulsified asphalts and AC 2.5 as bituminous materials in surface treatments *(3)*.

Another existing criterion to select binders includes viscosity. The literature recommends a series of kinematic viscosity values for binders used in surface treatments (Table 2) *(15)*.

Table 2. Kinematic Viscosities for a Successful Surface Treatment.

Kinematic Viscosity (cSt)	Problem Addressed
More than 1×10^{6}	Inadequate consistency for wetting
More than 1×10^{7}	Inadequate compaction
Less than 2×10^{4}	Scuffing on curves or accelerating zones
Less than 6×10^{3}	Scuffing on average traffic condition

Vickaryous and Ferguson suggest a limiting value for emulsified asphalts to control binder-aggregate adhesion based on the apparent viscosity of the residues obtained by distillation *(16)*. This proposed critical value is 50,000 Pa· s. According to this criterion, the temperature at which this value is met is the lowest temperature at which this binder will inherently adhere to the aggregate.

Other attempts to improve material selection correlated results of different adhesion tests to aggregate retention and surface treatment performance. Previous researchers established these relationships for the Wet Abrasion Test, Trafficulator, Seal Coat Debonding Test, and standard and modified Vialit tests *(15, 17, 18, 19, 20)*. To select the appropriate binders and aggregates for surface treatments, Walsh et al. developed a modified version of the SHRP Net Adsorption Test (NAT) (SHRP M-001) *(21)*. This procedure measures the affinity and sensitivity of aggregate-binder systems to moisture. Others developed surface energy measurements and models that consider intermolecular forces to explain the affinity between aggregate and binders *(22, 23)*.

Desired Properties

Shook et al. recommended the following binder characteristics required for a successful surface treatment *(24)*:

- fluid enough to allow uniform application,
- fluid enough to develop initial adhesion between binder and aggregate as well as to the underlying surface,

- viscous enough to retain aggregate when the road opens to traffic,
- viscous enough to prevent distortion in hot weather,
- fluid enough (not brittle) in cold weather to prevent aggregate loss,
- resistant to effects of sun light, and
- resistant to the combined action of traffic and water to avoid stripping.

EVALUATION SURVEY

As part of this study, researchers designed an evaluation survey to gather information about surface treatment practices in the state of Texas. The questionnaires were sent to all 25 TxDOT districts, two contractors, and four asphalt materials experts. Questionnaires focused on identifying frequently used materials and determining qualitative performance ratings of these materials in different climates. Surface treatment materials were evaluated on a 1- to 5-point scale (1 being poor and 5 good) in the following categories: water sealing, skid resistance, tire noise, aggregate retention, overall performance, and cost-effectiveness. Table 3 lists all categories evaluated in the questionnaires, and Appendix A provides actual survey forms.

Table 3. Categories in Evaluation Survey.

Categories	Subcategories	
Binder	• Supplier	• Modifiers
Aggregate	• Aggregate type • Shape	• Gradation
Surface Treatment	• Design methodology • Condition of existing surface	• Criteria for material selection
Traffic	• Traffic level	• Turning/accelerating zones
Distresses	• Distresses shown	• Possible causes
Evaluation	• Water sealant • Skid resistance • Tire noise • Appearance	• Aggregate retention • Overall performance • Cost-effectiveness
Other	• Material selection • Binder properties	• General recommendations

The response rate for the survey was 76 percent for the TxDOT districts and 66 percent for the contractors and asphalt materials experts. Figure 1 presents ratings for the overall performance of commonly used surface treatment binders. Appendix B provides ratings for the rest of the categories included in the evaluation survey.

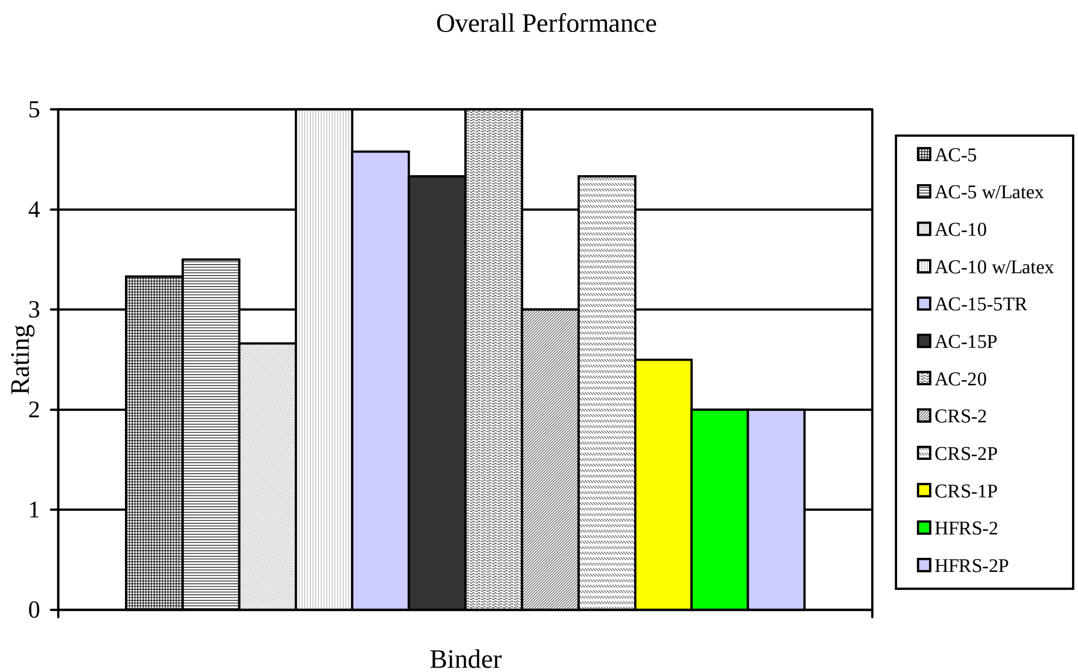


Figure 1. Overall Performance Ratings for Commonly Used Binders.

CHAPTER 3. EXPERIMENTAL DESIGN

Based on the information gathered from the literature and the evaluation survey, researchers developed an extensive laboratory testing program. This design included material selection of commonly used binders in surface treatments, investigation and analysis of recovery processes for asphalt emulsions, and standard and modified PG testing of the selected binders.

MATERIAL SELECTION

Researchers selected binders and aggregates based on the information from the TxDOT survey responses.

Binders

Researchers assembled a list of binders commonly used in Texas in surface treatments and their suppliers. They contacted these suppliers to check for availability of their products and requested materials. They also obtained binder materials known to have poor performance in Texas climatic conditions. Table 4 lists asphalt binders selected and used in this study by a supplier code letter.

Aggregates

Researchers obtained common aggregates in Texas using the same procedure followed with the binders. For this study they acquired crushed limestone, precoated crushed limestone, and lightweight aggregate.

Researchers performed a sieve analysis on the aggregates to verify the size of the material. Based on the results of this analysis, they identified two crushed limestone materials of TxDOT grade 4 and a single size (0.375 in (9.5 mm)) lightweight aggregate *(1)*.

Table 4. Selected Binders.

Binder Type	Supplier
CRS1P	E
CRS1P	B
CRS1P	D
CRS2	E
CRS2P	E
CRS2P	B
HFRS2	E
HFRS2P	E
AC1.5	C
AC3	C
AC5	A
AC5	F
AC5	C
AC5 with Latex (w/L)	C
AC10	A
AC10	C
AC10 with Latex (w/L)	C
AC15-5TR	F
AC15P	F
AC15P	E
AC20	C

LABORATORY TESTING

The extensive laboratory testing program included investigation of several recovery processes for asphalt emulsions and evaluation of physical properties of binders measured using existing PG equipment.

Recovery Process

A number of asphalt emulsions were among the binders commonly used in surface treatments in Texas. Since this study focused only on the properties of the binder after construction, recovery of the emulsion residue was required. Researchers revised several recovery processes for asphalt emulsions to identify an efficient, repeatable method to recover the residue from both unmodified and modified emulsions while minimizing aging and ensuring removal of all water. Researchers considered oxidation during recovery, water removal, viscosity of the residue, duration, and yield in selecting the recommended recovery method.

Researchers examined five recovery procedures: hot oven, rotavap, hot plate, stirred can, and distillation. They evaluated several characteristics for each of the methods: efficiency of removing water from the emulsion, preventing oxidation of the emulsion residue, and preventing deterioration of polymeric additives important to enhancing performance.

The hot oven method followed closely that of ASTM D 244-97C with the exception that nitrogen flowed over the sample to prevent asphalt oxidation and consequent hardening of the material. Researchers placed beakers 8.4 cm in diameter and 12.3 cm in height, each containing 50 g of asphalt emulsion, in an oven at 163 °C with nitrogen flow. After two hours, they stirred the emulsions well with a glass rod and allowed them to dry for another hour. They then stored the residues in ointment tins for subsequent analysis.

The rotavap method followed that of ASTM D 5404-97 as modified by Burr et al. to provide a sample collection container that is an ointment tin measuring 5.4 cm in diameter by 3.4 cm in height (*25*). Researchers placed 16 g of emulsion in the tin and evaporated for 30 minutes with the rotavap bath at 100 °C and then for another 70 minutes with the bath temperature raised to 163 °C. They provided a vacuum and nitrogen to prevent contact with oxygen and resulting oxidation. This method was effective but produced a small amount of recovered material (approximately 10 g).

The hotplate method was provided by TxDOT, Construction Division, Materials and Tests. Researchers placed ointment tins, each containing 20 g of emulsion, on a hot plate set to 180 °C. They stirred the emulsion periodically for one hour. With this method, researchers were particularly concerned with the effectiveness of water removal and asphalt oxidation.

ASTM 244-97C documents the distillation method. Researchers placed emulsion (200 g) into an aluminum alloy still and heated it with a ring burner. They distilled the material at 215 °C for 45 to 60 minutes and then at 260 °C for another 15 minutes.

Researchers developed the stirred can method for this study. This method recovered the largest amount of asphalt of any of the methods. Researchers placed emulsion (1250 g) in a gallon can and wrapped the can in heating tape. They used an impeller to continuously stir the emulsion. Then they bubbled nitrogen through the residue to hasten water removal as soon as possible without inducing foaming.

Researchers evaluated all five methods for water removal (by weight), for oxidation (by Fourier-Transform Infrared analysis (FTIR), and for residual water and polymer degradation (by viscosity). Table 5 shows typical results from this evaluation.

Table 5. Evaluation of Emulsion Recovery Methods.

Method	Mass Charged (g)	Mass Loss (%)	Carbony Area (FTIR)	Viscosity at 60 °C (Poise)
Hot Oven	50 x 3 beakers	30.1	0.42	860
Rotavap	16	31.1	0.40	816
Hot plate	20 x 4 tins	29.3	0.43	415
Distillation	200	29.2	0.33	383
Stirred Can	1250	30.9	0.39	742

Researchers judged the rotavap method as providing the best recovery, combining maximum water removal with minimum asphalt oxidation. The hot oven method with the nitrogen blanket also did a good job with the recovery. The hot plate method, however, had a problem with oxidation and incomplete water removal. Residual water resulted in a significantly reduced asphalt viscosity. The distillation method also produced a material having a greatly reduced viscosity compared to that from the rotavap method. Researchers believe this is due to polymer degradation caused by the high temperatures utilized in this method, in addition, perhaps, to some residual water. The stirred can method produced nearly the same water removal, limited oxidation, and recovered asphalt viscosity as the rotavap procedure. At the same time, this method produced much more recovered material, 800 g per batch in approximately 170 minutes, making it by far the most efficient method.

After evaluating each method by comparing the properties described, researchers selected the stirred can method as the recommended recovery procedure and used it throughout the project to produce emulsion residue for further laboratory testing. To summarize, the key points of the procedure are as follows:

- 1200 g of emulsion is poured in a one-gallon can and constantly stirred.
- A nitrogen blanket is used to avoid oxidation.
- Temperature: 163 °C.

- Time: 170 minutes.
- Yield: approximately 800 g.

Effect of Emulsifying Agent on Aging

Oxidative aging is a critical factor in establishing asphalt durability. As asphalts oxidize, both their viscosity and their elastic stiffness increase, thereby leading to a more brittle material. After extensive aging, the binder cannot sustain normal loads (due either to traffic or temperature fluctuations) without fracture. In addition, aging produces more polar materials and this likely leads to increased susceptibility to moisture damage.

Asphalts at the surface of a pavement are especially susceptible to aging because they are exposed to the highest temperatures and therefore the most rapid aging rates. Furthermore, they are subjected to the greatest concentrated loads, exerted at the edge of a vehicle's tire. So, researchers are especially concerned if a surface treatment binder is extraordinarily susceptible to oxidative aging. In this regard, they are interested if emulsifying agent, or other components in surface treatment binders not in conventional asphalts, adversely affects the aging rate and thereby leads to premature failure.

In a brief study researchers looked for evidence to determine if emulsion residues age differently from their base asphalts. They aged a base CRS-1P material and its corresponding recovered emulsion residue at 60 °C for two, four, and six months and determined the extent of oxidation (carbonyl area) and hardening (η^*) for each aging time. They measured dynamic viscosity data over a range of frequencies and temperatures and determined a 60 °C master curve. From this curve, researchers obtained the dynamic viscosity at 60 °C and 0.1 rad/s that represents the low shear rate limiting viscosity.

Figures 2 through 4 show the results for the base CRS-1P material and its corresponding recovered emulsion residue. Figures 2 and 3 illustrate carbonyl area and viscosity increases with aging time. Figure 4 shows how hardening is related to oxidation. The slopes of these plots represent the rate of oxidation, the rate of hardening, and the hardening susceptibility, respectively. Each of these properties is characteristic of the asphalt, and differences in aging reactions or mechanisms caused by the emulsifier (or polymer, or other component) likely would be evident in one or more of these plots. These plots also show data points for unaged material, but these points are not included in the trendlines because it is typical for asphalts to undergo short-term rapid aging by a different mechanism.

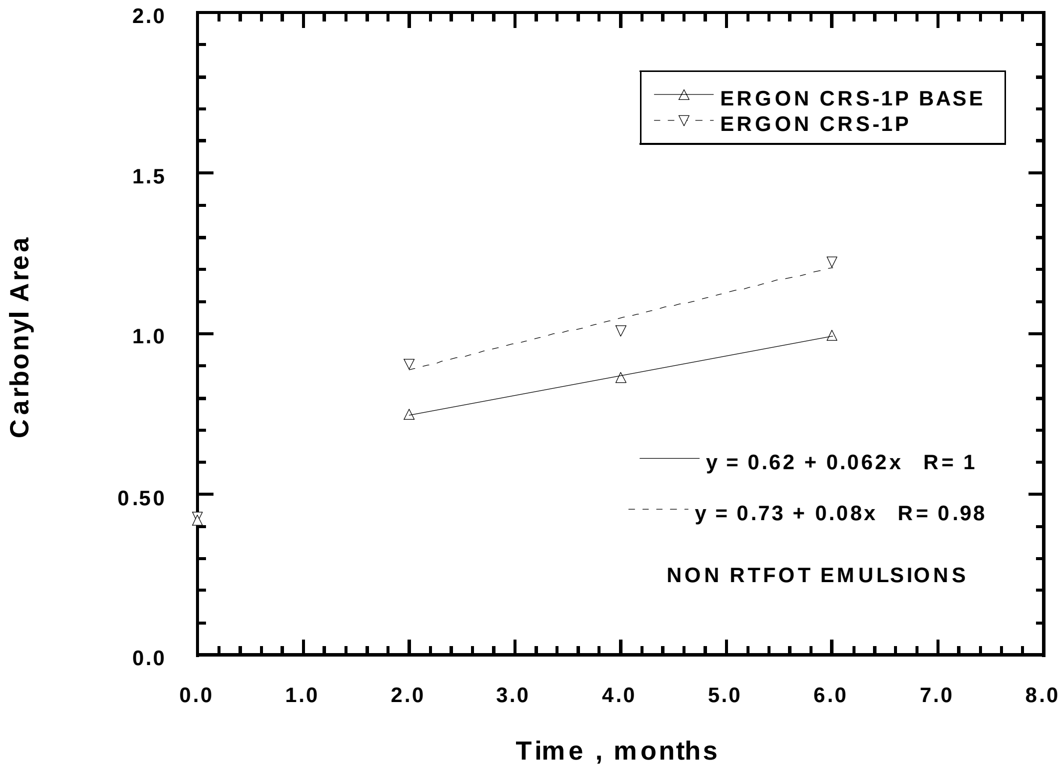


Figure 2. Effect of Emulsifying Agent on Carbonyl Area.

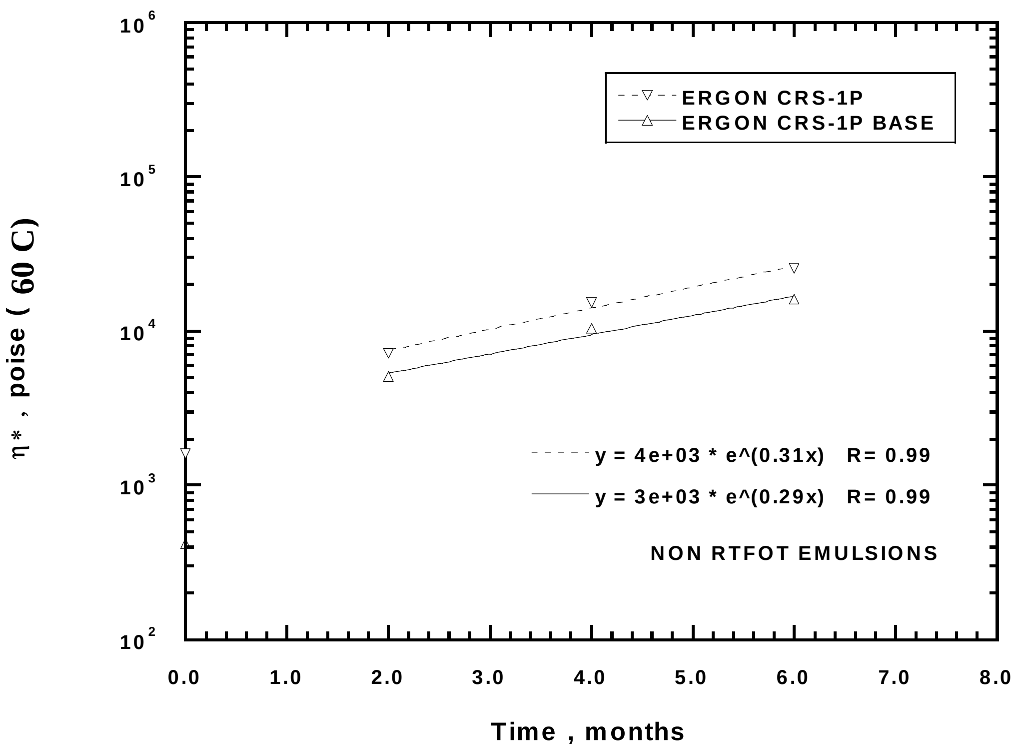


Figure 3. Effect of Emulsifying Agent on Viscosity.

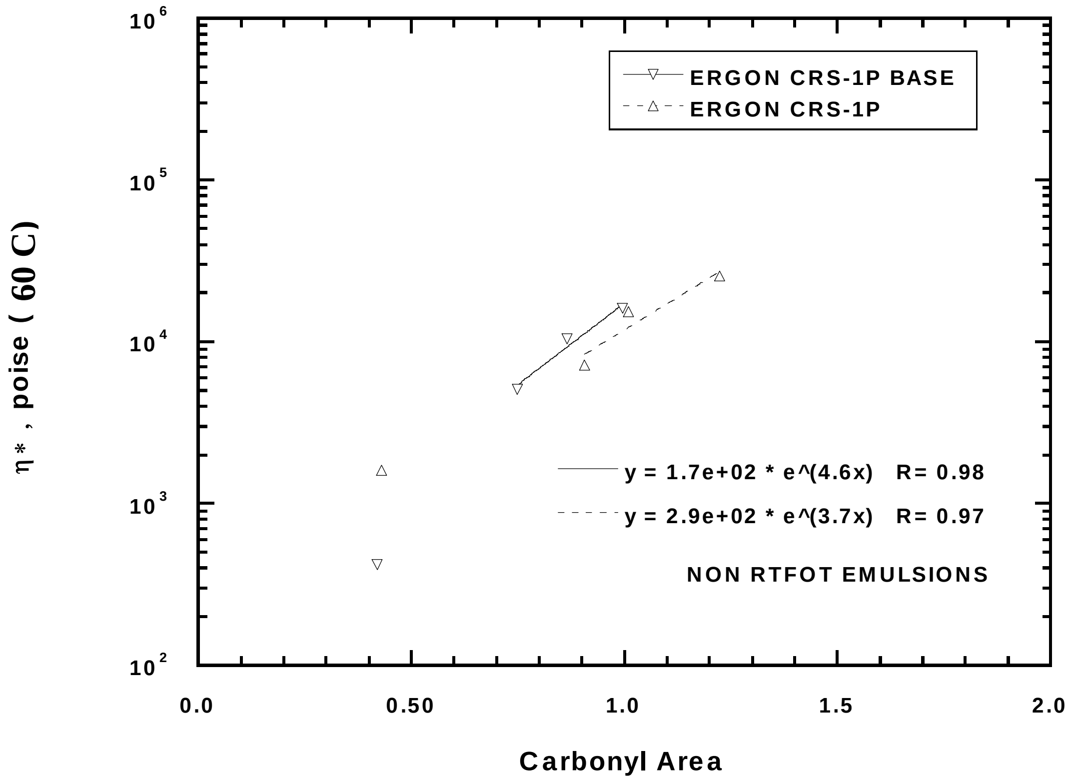


Figure 4. Effect of Emulsifying Agent on Hardening Susceptibility.

Researchers noted that for all three of these plots, the slopes are almost equivalent for the base material and the recovered emulsion residue. The hardening rates are virtually identical, while the oxidation rates and hardening susceptibilities differ from their mean by approximately 10 percent.

Although this was a very limited study, researchers conclude that these results strongly suggest that the added components in emulsions do not affect an asphalt's oxidation mechanism or kinetics.

PG Testing

The PG binder specification utilizes procedures and laboratory equipment that measure fundamental physical properties related to the performance of HMAC. Researchers utilized equipment from this specification to measure physical properties of selected surface treatment binders to develop the SPG specification. First, they completed the standard PG testing procedure for all selected binders. Then, they utilized a Modified Performance Grading testing procedure that takes into consideration the differences between HMAC and surface treatments for the same materials.

Adhesion Tests

Although adhesion characteristics are not directly related to the physical properties of binders, they are important and have some influence in controlling the performance of surface treatments.

Researchers conducted an evaluation of two adhesion tests (Vialit Test and a Wet Abrasion Test) to determine their feasibility and applicability (*17*, *19*, *26*). They prepared binder and aggregate samples and tested these materials combined based on the results of a chip seal design *(11)*. They determined properties of the aggregates as part of the design methodology. Vialit and Wet Abrasion trial results did not provide conclusive information in terms of distinguishing between good and poor performance between different materials. In addition, the test results were not consistent. Because of these problems and the rather qualitative nature of these tests, researchers decided to take a different approach to assess relevant binder properties.

PAVEMENT SURFACE TEMPERATURE ANALYSIS

The PG binder specification is based on physical properties that are directly related to performance. The PG system has constant limiting values for all binders and specifies grades based on the maximum and minimum test temperatures at which the binders meet these limiting values *(6)*. These maximum and minimum temperatures represent the range of pavement temperatures over which the binders are expected to perform adequately. Since the PG grading system depends on pavement temperatures, researchers completed an analysis of the climate in Texas.

The standard PG procedure specifies that the high pavement design temperature be determined 20 mm below the surface. The low pavement design temperature is found at the pavement surface *(6)*. For this analysis, researchers calculated both high and low pavement temperatures at the pavement surface to reflect critical conditions for surface treatments.

High-Temperature Analysis

Researchers analyzed climate information obtained from the LTPPBind V2.1 database to determine high and low pavement surface temperatures in Texas. They used the SHRP high-temperature model to calculate pavement surface temperature using the high 7-day air temperature and the latitude of the listed weather stations in Texas. This model calculates surface pavement temperature based on the net heat flow at the pavement surface *(27)*:

Net heat flow = [direct solar radiation] + [diffuse radiation] ± [convection] ± [conduction] - [black-body radiation]

To compute the temperature of the hottest 7-day period, the SHRP model also takes into account solar absorption, radiation transmission through air, atmospheric radiation, and wind speed. The values used in the model for these variables are listed as follows *(27)*:

- Solar absorption = 0.90.
- Transmission through air = 0.81.
- Atmospheric radiation = 0.70.
- Wind speed = 4.5 m/s.

The SHRP model then uses the following equation to calculate pavement temperature as a function of air temperature and latitude, where temperature at the surface (T_{surf}) and air temperature (T_{air}) are expressed in °C and the latitude (lat) is in degrees *(27)*:

$$T_{surf} - T_{air} = -0.00618\ lat^2 + 0.2289\ lat + 24.4 \quad (1)$$

This model also considers the possibility of calculating temperatures at different levels of reliability (Eq. 2). T_{pav} is the high pavement temperature at a particular reliability level (°C), T_{surf} is the high pavement surface temperature (°C), S_{air} is the standard deviation of the high 7-day mean air temperature (°C), and z is the z-value of the standard normal distribution. Assuming a normal distribution for the temperatures in Texas, researchers calculated pavement surface temperatures for 50 and 98 percent reliability levels for all weather stations in Texas using the following equation:

$$T_{pav} = T_{surf} + z \times S_{air} \quad (2)$$

They then separated weather stations into TxDOT districts and determined the average high pavement surface temperature at the corresponding level of reliability for each district.

Low-Temperature Analysis

Researchers utilized the SHRP low-temperature model for the low-temperature analysis. This model assumes that the pavement surface temperature is equal to the minimum air temperature as shown in the following equation *(27)*:

$$T_{surf} = T_{air} \tag{3}$$

They also used the following SHRP model for low temperature described previously to determine the average low pavement surface temperature at 50 and 98 percent reliability levels for all TxDOT districts:

$$T_{pav} = T_{air} - z \times S_{air} \tag{4}$$

Figure 5 shows the average pavement surface temperature ranges (high-low) for all 25 TxDOT districts. The two rows shown for each district in Figure 5 indicate 98 percent (upper) and 50 percent (lower) reliability levels. Table 6 contains surface pavement temperature ranges at 98 percent reliability and overall binder performance and chip retention ratings for some of the TxDOT districts that responded to the survey.

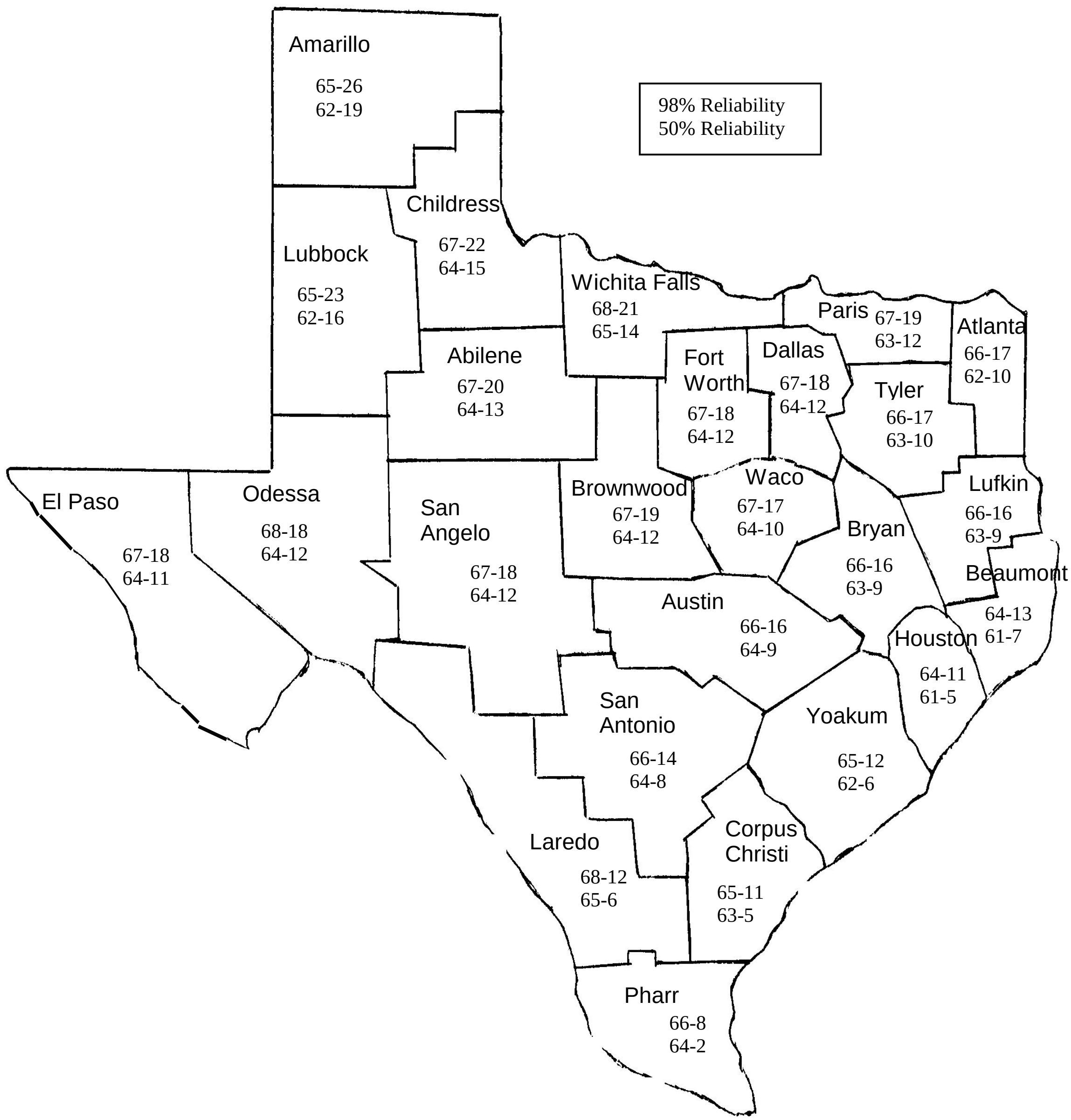


Figure 5. Pavement Surface Temperatures in Texas.

Table 6. Performance Ratings for Surface Treatment Binders in Texas.

Binder Summary t (representative districts)					
District	Surface Temperature Range (98% reliability) °C	Binder Type-Supplier	Overall Rating	Chip Retention	Performance
Laredo	68-12	AC15P F	5	5	Good
		AC15-5TR F	5	5	Good
		AC5 F	4	4	Good
Bryan	66-16	AC15P F	4	4	Good
		AC15-5TR F	4	4	Good
Brownwood	67-19	CRS2, CRS2P E	4	4	Good
		AC15-5TR F	5	5	Good
		AC5 F	4	4	Good
Childress	67-22	AC5 w/L F	3	3	Good
		AC15-5TR F	5	5	Good
		AC5 F	4	4	Good
Fort Worth	67-18	CRS2, CRS2P E	5	5	Good
		AC10 w/L C	5	5	Good
		AC15P E	4	3	Good
		AC15-5TR F	5	5	-
Amarillo	65-26	AC5 A	2	1	Fair
		AC10 A	2	1	Fair
		CRS2 E	2	2	Fair
		CRS2P E	3	3	Fair
		AC15-5TR F	4	4	Fair
		AC15P E	4	4	Fair
		AC5 w/L C	3	3	Fair
San Angelo	67-18	AC15P F	4	4	Good
Abilene	67-20	AC5 C	2	2	Fair
		AC10 C	2	2	Fair
		AC5 w/L C	4	4	Good
		AC15-5TR F	5	5	Good
Atlanta	67-17	CRS2P B	4	5	Good
		AC15-5TR F	4	5	Good
Austin	66-16	AC15-5TR F	5	5	Good
		AC15P F	5	5	Good
		HFRS2 E	-	-	Fair
		HFRS2P E	2	2	Fair
Beaumont	64-13	CRS2P E	5	5	Good
		AC5 w/L C	4	4	Good
		AC10 C	4	4	Good
Dallas	67-18	AC5 w/L C	3	3	Fair
Yoakum	65-12	AC15P F	4	4	Good
		AC15-5TR F	4	4	Fair
		CRS1P D	2	2	Poor

Note: - Information not provided

STANDARD PG TESTING AND GRADING

Researchers followed procedures described in American Association of State Highway and Transportation Officials (AASHTO) MP1 to grade asphalt cements and emulsion residues *(28)*. They used the rotational viscometer (AASHTO TP48) at 135 °C and 20 rpm to measure viscosity of unaged asphalt cement binders to ensure pumping and handling capabilities *(28)*. They performed Dynamic Shear Rheometer (DSR) tests (AASHTO TP5) on unaged and short-term aged material from the Rolling Thin Film Oven Test (RTFOT) (ASTM D 2872) *(5, 28)*. The results from these DSR tests in terms of complex modulus (G*) and phase angle (δ) established the high-temperature grade of the binders.

Researchers long-term aged material in the PAV (AASHTO PP1) that had previously been short-term aged in the RTFOT (ASTM D2872). They then conducted DSR tests to determine intermediate-temperature properties *(28)*. Flexural stiffness and m-values obtained from Bending Beam Rheometer (BBR) testing (AASHTO TP1) of short- and long-term aged material established the low-temperature grade *(28)*.

MODIFIED PG TESTING AND GRADING

The Modified Performance Grading system consisted of standard PG testing as described in AASHTO MP1 with some modifications. These modifications account for differences between surface treatments and HMAC in terms of distress types, construction methods, and exposure to environmental conditions. This section describes the modifications.

Pavement Design Temperatures

Pavement temperatures play a key role in the PG system because the grading process itself is based upon these temperatures. Researchers conducted an evaluation of the PG design temperatures to assess whether these correspond to field conditions for surface treatments.

High Pavement Design Temperature

As mentioned, the standard PG procedure specifies that the high pavement design temperature be calculated 20 mm below the surface. This depth represents critical conditions to account for rutting in the standard PG system. Based on the information search, researchers did not consider rutting a common distress in surface treatment applications. Thus, instead of using pavement temperatures at 20 mm, they included pavement temperatures measured at the surface in the Modified Performance Grading system for the high pavement design temperature, since these temperatures reflect field conditions for surface treatments.

Low Pavement Design Temperature

The standard PG procedure uses temperatures measured at the pavement surface to establish the low pavement design temperature. This practice simulates critical field conditions for surface treatments also; therefore researchers considered the same low pavement design temperature appropriate for the Modified Performance Grading system.

Temperature Increments

Based on the results from the pavement temperature analysis in Texas, researchers set test temperatures for the Modified Performance Grading system to 3 °C increments for both high and low design temperatures, as opposed to the 6 °C increments utilized in the standard PG specification. They selected narrower temperature ranges to discriminate performance on a finer scale.

Testing Procedures

Researchers also altered some of the aging and testing procedures and conditions included in the standard PG system in the Modified Performance Grading to simulate conditions observed in surface treatments.

Aging States

As part of adapting the PG testing to be more suitable for surface treatment binders, researchers had to modify some of the aging procedures to simulate actual field conditions for these binders. Based on the relatively low temperature at which emulsions are sprayed and the shorter period of time that asphalt cements are kept at high temperatures before construction, researchers removed the RTFOT from the Modified Performance Grading system. With this change, they determined PG properties on only unaged and long-term aged binders.

Application Properties

The standard PG system uses the rotational viscometer to ensure pumping and handling capabilities of asphalt cements during mixing. This test is conducted at one temperature (135 °C) for all binders. Researchers assessed this approach as inappropriate for the Modified Performance Grading system because asphalt cements are heated to higher temperatures over a wider range to allow for uniform spraying on the pavement. Spraying temperatures depend on binder consistency, and there is not a common spraying temperature for all binders. For this reason, the Modified Performance Grading system includes rotational viscometer tests at multiple temperatures to obtain proper spraying temperatures for surface treatment binders.

High-Temperature Testing

The standard PG procedure utilizes DSR testing on short-term aged binder (RTFOT residue) and on unaged binder to account for rutting. Short-term aged binder is tested in the DSR because this aging state represents the asphalt binder condition just after placement and before long-term aging takes place. The standard PG specification also includes DSR testing of unaged binders to make sure that those binders that do not age as much during production and mixing have sufficient resistance to permanent deformation (*29*). Since researchers removed the RTFOT aging procedure from the Modified Performance Grading system, this system includes DSR testing on unaged binders only to reflect critical conditions for early-age surface treatments.

Intermediate-Temperature Testing

Researchers implemented an additional variation to the standard PG procedure for intermediate-temperature testing. The standard PG system requires that long-term aged binder be tested in the DSR to address fatigue cracking of HMAC. Surface treatments are thin applications, and they are not likely to exhibit this form of distress. Instead, aggregate loss can occur at these temperatures. To address this type of distress in the Modified Performance Grading system, researchers decided to perform DSR tests at intermediate temperatures on unaged binders. Again, they selected this aging state to represent the worst case for aggregate loss at intermediate temperatures. The standard PG system includes DSR testing at several different temperatures within the intermediate-temperature range. For the Modified Performance Grading system, researchers performed this test at only one temperature representative of intermediate temperatures in Texas.

Low-Temperature Testing

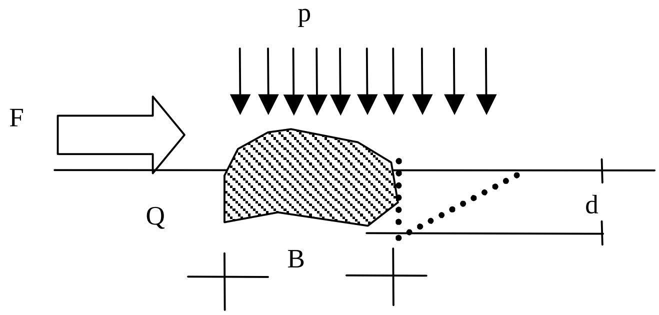
Researchers also changed the determination of properties at low temperatures. The standard PG BBR procedure determines stiffness and m-value at a loading time of 60 seconds in a test performed at a temperature 10 ºC warmer than the expected minimum surface pavement temperature. The basis for these testing conditions is a critical condition at a long loading time to simulate thermal cracking of HMAC and the application of the principle of time-temperature superposition. Since thermal cracking is not of concern in surface treatments, researchers used the stiffness measured at the fastest loading time possible using existing BBR equipment (8 seconds) to simulate critical traffic loading conditions and the actual test temperature to determine the low-temperature grade of binders in the Modified Performance Grading system. They performed this testing procedure on material aged only in the PAV.

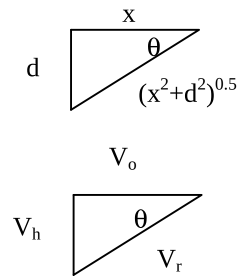
UPPER BOUND THEOREM

Plasticity theory utilizes the Upper Bound Theorem (UBT) to estimate failure conditions *(30)*. The UBT states that if an estimate of the plastic collapse load of a body is made by equating the internal rate of dissipation of energy to the rate at which external forces do work in a proposed deformation mechanism, the estimate will be greater than or equal to the actual value *(30)*.

Researchers analyzed a proposed failure mechanism for an aggregate embedded in a surface treatment binder using the UBT approach to estimate the required shear strength to hold the aggregate in place. Variables analyzed in the postulated mechanism included shear strength of the binder (Q), transverse tire contact force (F), vertical tire contact stress (p), aggregate size (B), and aggregate embedment (d). By equating the internal rate of dissipation of energy and the work done by the external forces using virtual velocities and dissipation surfaces of the sliding block, researchers evaluated the assumed failure mechanism. Figure 6 presents this assumed failure mechanism, the analysis approach, and the final dimensionless equation.

The UBT was used in the SPG specification as a tool to analyze the assumed failure mechanism to corroborate the limiting values for the parameters controlling performance.





$$Sin\theta = \frac{V_h}{V_r} = \frac{d}{\sqrt{x^2+d^2}}$$

$$Cos\theta = \frac{V_o}{V_r} = \frac{x}{\sqrt{x^2+d^2}}$$

$$Tan\theta = \frac{V_h}{V_o} = \frac{d}{x}$$

$$FV_o - pBV_h - pxV_h = QV_r\sqrt{x^2+d^2} + QV_h d$$

$$FV_o - pB(V_o\frac{d}{x}) - px(V_o\frac{d}{x}) = \frac{QV_o}{x}(\sqrt{x^2+d^2})^2 + Q(V_o\frac{d}{x})d$$

$$\frac{F}{dQ} = \frac{d}{x} + \frac{x}{d} + \frac{d}{x} + \frac{p}{Q}\frac{B}{d}\frac{d}{x} + \frac{p}{Q} \qquad F' = \frac{F}{dQ} \qquad x' = \frac{x}{d}$$

$$F' = x' + \frac{1}{x'}(2 + \frac{p}{Q}\frac{B}{d}) + \frac{p}{Q} \qquad \frac{\partial F'}{\partial x'} = 0$$

$$\frac{F}{dQ} = 2\left(2 + \frac{p}{Q}\frac{B}{d}\right)^{\frac{1}{2}} + \frac{p}{Q} \qquad F = \tau B$$

$$\frac{\tau}{Q}\frac{B}{d} = 2(2 + \frac{p}{Q}\frac{B}{d})^{\frac{1}{2}} + \frac{p}{Q}$$

Figure 6. Failure Mechanism Analysis and Dimensionless Equation.

CHAPTER 4. SPG ANALYSIS AND RESULTS

Researchers identified important physical properties that control the performance of surface treatments during the information search. They measured these properties in the laboratory testing program and analyzed them in conjunction with the performance ratings and corresponding surface pavement temperature ranges to form the basis of the SPG specification.

They divided the data analysis into four major sections to conclude with the development of the SPG specification. These sections represent critical situations that surface treatment binders undergo during construction and in-service. Based on the information gathered in the literature review and the results of the evaluation survey, the performance of surface treatment binders depends mainly on application (spraying of the material) and high-, intermediate-, and low-temperature behavior of the binder.

SPG SPRAYING

Binder consistency during application is an important factor in surface treatment performance. Binders 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 sprayed too hot, they are prone to flow, causing the same effect. Extremely high temperatures can also increase aging and alter the binder.

Spraying is especially significant for asphalt cements due to the fact that spraying temperatures are higher than those required for asphalt emulsions. Viscosity ranges recommended in the literature for either type of binder vary from 0.05 to 0.20 Pa·s *(7, 9, 31, 32)*. Researchers used the rotational viscometer (AASHTO TP48) for a representative group of asphalt cements to obtain temperatures corresponding to these ranges *(28)*. Figure 7 shows the results for AC10 C, AC15-5TR F, AC15P E, and AC20 C.

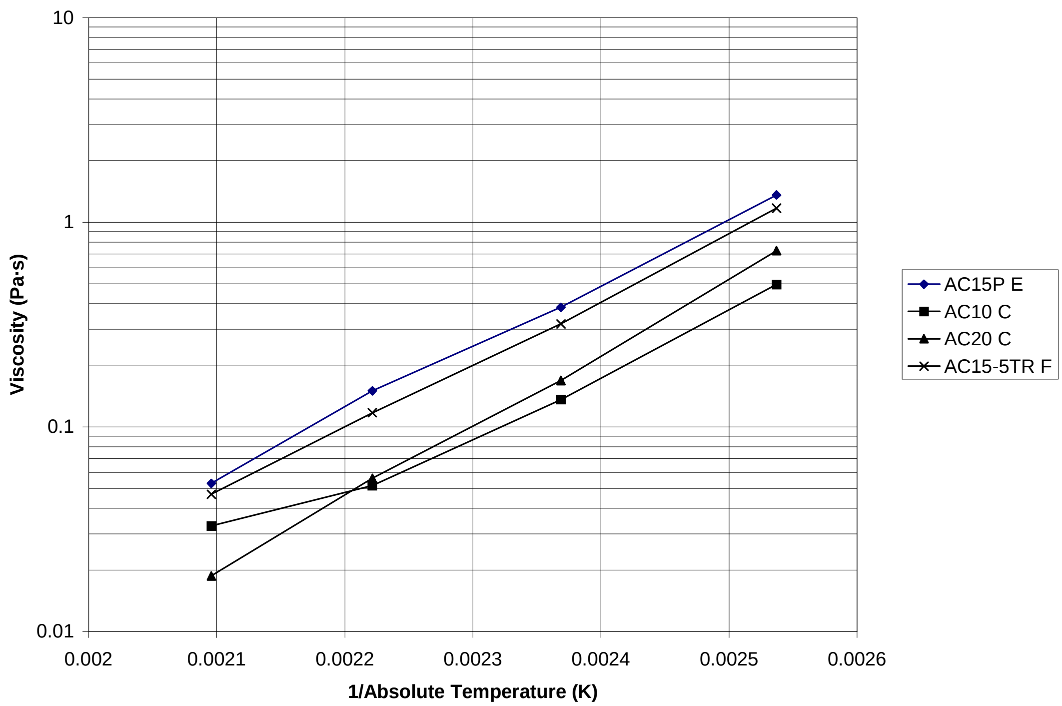


Figure 7. Rotational Viscometer Results for Selected Asphalt Cements.

Based on the results presented in Figure 7, researchers recommend spraying temperatures corresponding to viscosities between 0.10 and 0.15 Pa·s for inclusion in the SPG specification. They also set a maximum temperature of 180 ˚C (minimum 1/absolute temperature = 0.0022) to prevent alteration of the binder and modifiers.

SPG HIGH TEMPERATURE

From the information gathered in the survey, researchers identified aggregate loss and bleeding as a consequence of aggregate loss as the primary performance-related distresses observed at high temperatures in surface treatments. These distresses arise principally when the shear resistance of the binder is inadequate to hold the aggregate in place under traffic forces. Researchers conducted an analysis to determine the binder property that controls this type of distress.

The PG binder specification uses $G^*/\sin\delta$ as the high-temperature parameter based on the fact that the amount of work dissipated in a load cycle at a constant stress is inversely proportional to G*/sin δ *(29)*. This implies that high values of G*/sin δ will reduce permanent deformation. Since aggregate loss at high temperatures in surface treatments is also a result of binder deformation and inadequate stiffness, researchers also selected G*/sin δ for the SPG specification as the high-temperature property controlling this form of distress. G* represents a measure of the resistance of the binder to shearing, and δ takes into account viscous and elastic behavior.

For the Modified Performance Grading high-temperature testing procedure, researchers also selected frequency (10 rad/s) and strain (10-12 percent) values used in standard PG testing to reflect critical loading and restrain binders to behavior within the linear viscoelastic (LVE) range. They also established that the critical aging state of the binder to determine high-temperature properties is the unaged state.

Researchers analyzed performance ratings and corresponding Texas climate data (Table 6) in conjunction with Modified Performance Grading DSR data at multiple temperatures to set the limiting value for G*/sin δ. With only a few exceptions, a threshold of 0.750 kPa separated binders that performed well (overall performance rating of 5) and those that did not (overall performance rating of 1 or 2) (Table 6). They assumed that exceptions may be related to poor performance due to construction. These exceptions also included a relatively uncommon material (HFRS 2P). This assumption is corroborated by the fact that most exceptions met the recommended specification but did not agree with the general performance rating.

The UBT provided a more theoretical basis for selection of this limiting parameter. First, researchers generated a chart of complex shear modulus (G*) versus temperature for all binders. Based on performance ratings and corresponding climate data, they selected a G* that reflected good performance. Subsequently, typical values of inputs to the UBT equation were used to calculate a range of required Q values (Table 7). The selected G* corresponded to a shear stress of 0.0750 kPa (assuming 10 percent strain) that fell within the calculated range for Q, the limiting stress value. Thus, G*/sin δ of 0.750 kPa (with sin δ values near one) was selected as the limiting stiffness value for the high-temperature grade based on this separate, more fundamental criteria. Figure 8 depicts DSR results for all binders and the high-temperature limiting value for the SPG.

Table 7. UBT Results for High-Temperature Analysis.

B/d Ratio	Transverse Tire Stress (τ) (kPa)	Vertical Contact Stress (p) (kPa)	Required Shear Strength Range (Q) (kPa)
2.28	317.15	689.47	0-0.100
2.28	296.47	689.47	
2.28	296.47	661.89	
1.90	317.15	689.47	
1.90	296.47	689.47	
1.90	296.47	661.89	

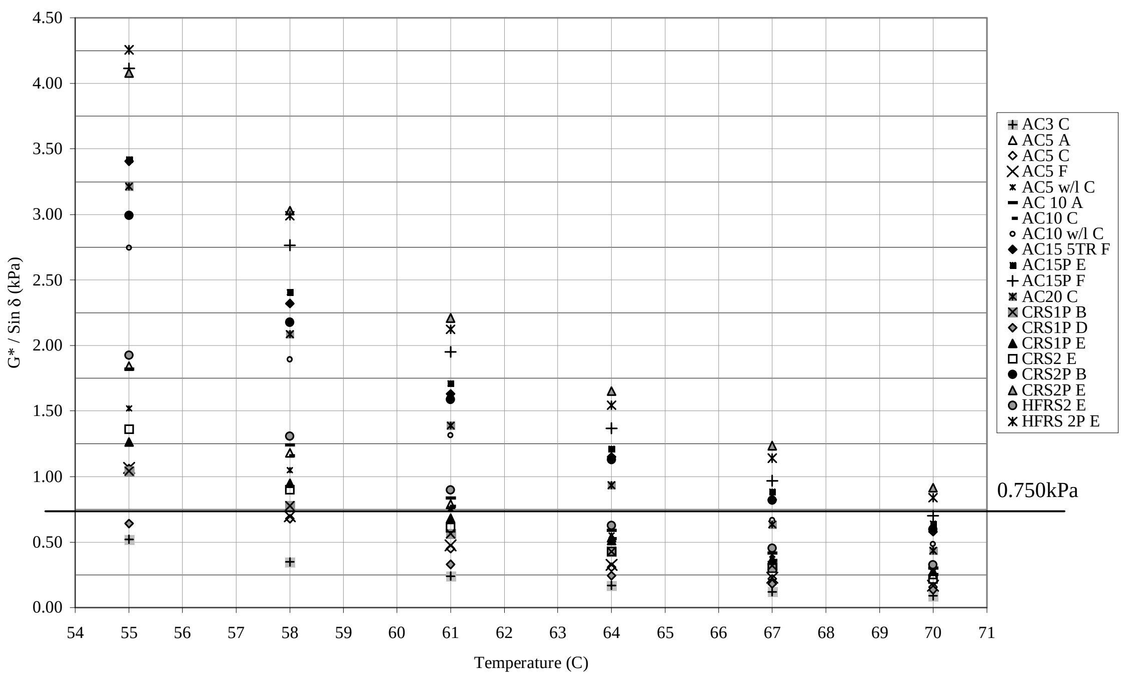


Figure 8. DSR Results and Proposed Limiting Value.

SPG INTERMEDIATE TEMPERATURE

Researchers used a methodology similar to that followed in the high-temperature analysis to account for aggregate loss at intermediate temperatures. They selected a temperature of 25 ˚C as representative of the intermediate-temperature spectrum in Texas. A comparison of DSR test results at 25 ˚C (10 rad/s, 1 percent strain) and UBT data established a limiting value. For these temperatures, this approach did not discriminate between those binders that performed well from those that did not. Every binder except one exhibited stresses greater than the limiting stress value calculated from the UBT equation. Table 8 shows the results of this approach.

Table 8. UBT Results for Intermediate-Temperature Analysis.

Binder	Measured Stress (25°C, 1% strain, and 10 rad/s) (kPa)	UBT Estimation of Q (kPa)
AC1.5 C	0.537	2.00
AC5 C	2.860	
AC10 C	7.180	
AC10 w/L C	4.870	
AC15P E	4.070	
CRS2P E	2.620	

These results did not correspond with available information that suggests most surface treatment failures occur at either high or low temperatures. Thus, at this time researchers excluded an intermediate-temperature property from the final recommended SPG. The lack of agreement was possibly due to an erroneous assumption of the failure mechanism or measurement of a property that does not control performance at intermediate temperatures.

SPG LOW TEMPERATURE

Researchers also identified the primary distress in surface treatments at low temperatures as aggregate loss. This problem occurs when the binder stiffness is too high, causing fracture under loading action. Researchers considered G* the material property controlling this form of distress. Since the standard PG system does not include testing equipment to obtain this value, they used BBR test results as a surrogate to analyze binder properties controlling aggregate loss at low temperatures.

Based on data gathered in the information search, the critical aging time for binders used in surface treatments is approximately one year, with failure of the majority of surface treatments either in the first summer (high temperature) or winter (low temperature).

To determine the amount of PAV time needed to simulate aging through the first winter, researchers obtained two different one-year-old field samples of each of two common binders (CRS2P and AC15-5TR) and analyzed these materials using FTIR spectroscopy. They sampled each of the two binders from two highways: the CRS2P from Routes 287 and 255 and the AC15-5TR from US Routes 183 and 77. They also aged the CRS2P material in a 60 °C environmental room to determine an approximate equivalence between field, PAV, and environmental room aging. They aged material in the environmental room in 1 mm thick films to minimize the effect of oxygen mass transfer effects.

Researchers extracted the binder from the surface treatment samples by washing with an 85 percent toluene / 15 percent ethanol mixture in a beaker. They then performed multiple washings of the aggregate followed by filtration and recovery in a rotavap in accordance with the procedure of Burr et al. to produce the recovered binder (*33*).

By performing infrared analyses of the recovered binders and the PAV and environmental room aged binders, researchers compared the extent of oxidation. Figures 9 through 13 show infrared spectra of the carbonyl band and adjoining aromatic band for the various materials.

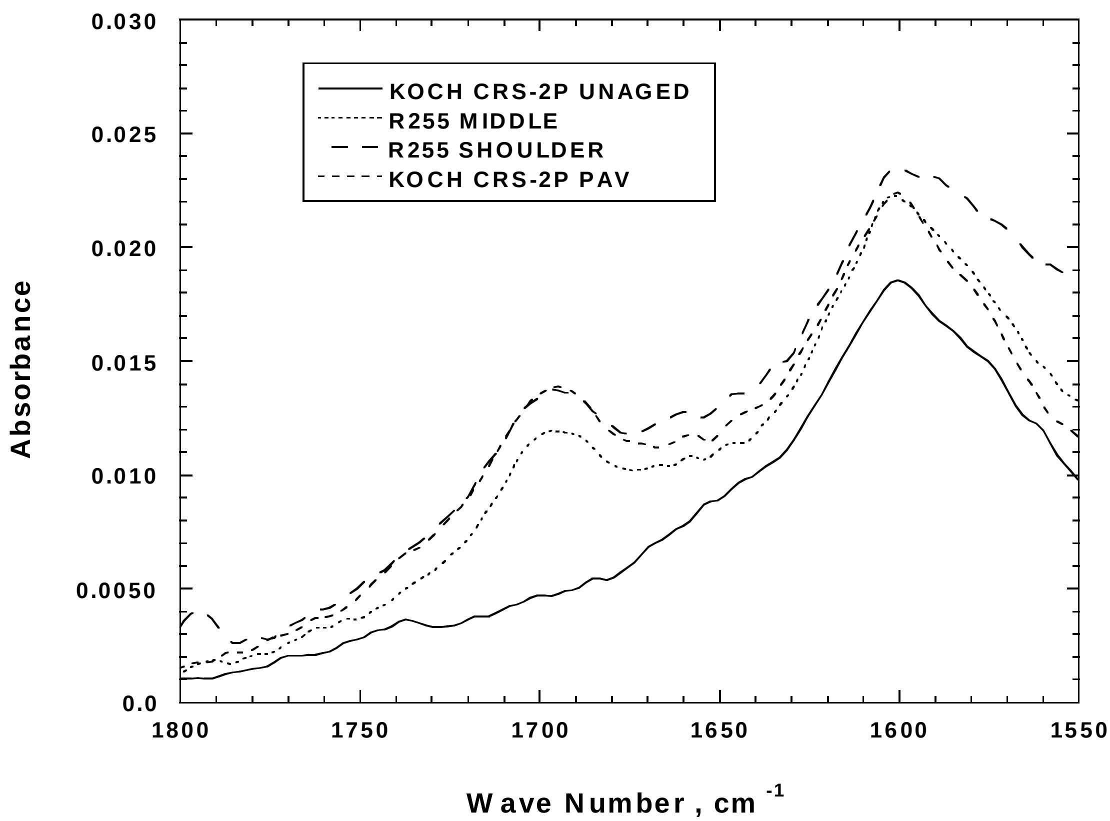


Figure 9. CRS2P Aging on Route 255 Versus PAV Aging.

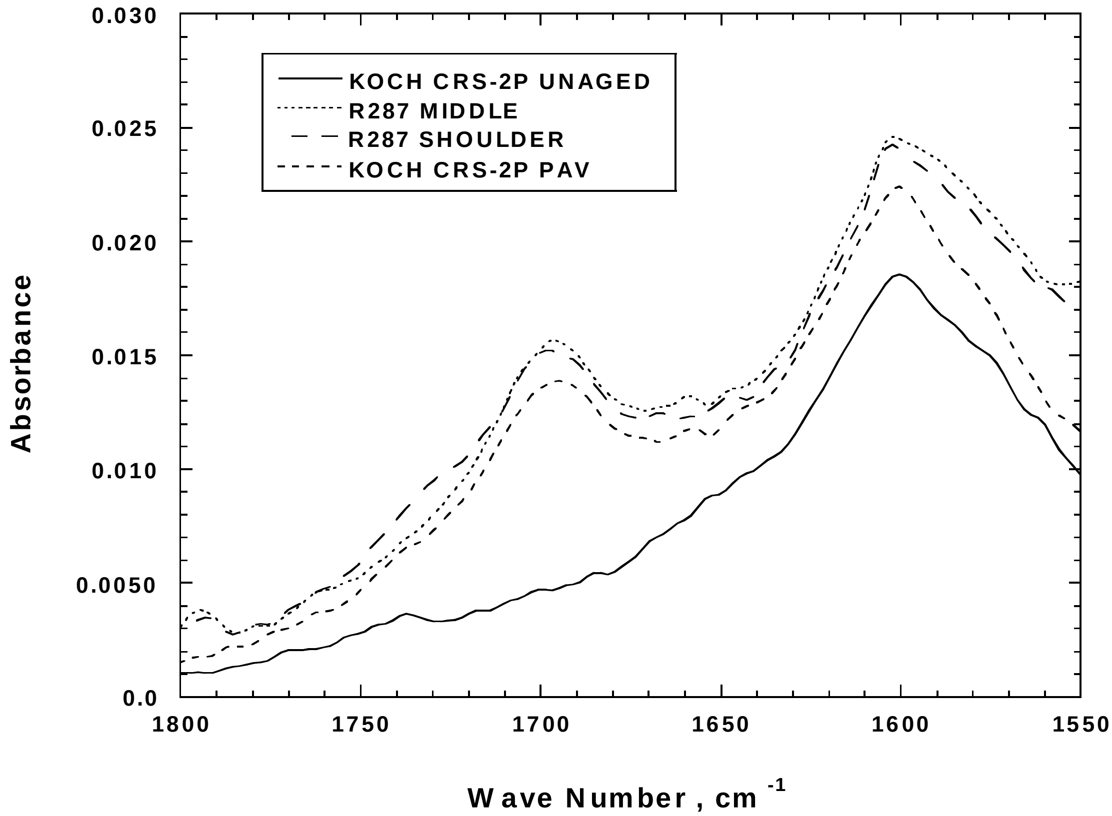


Figure 10. CRS2P Aging on Route 287 Versus PAV Aging.

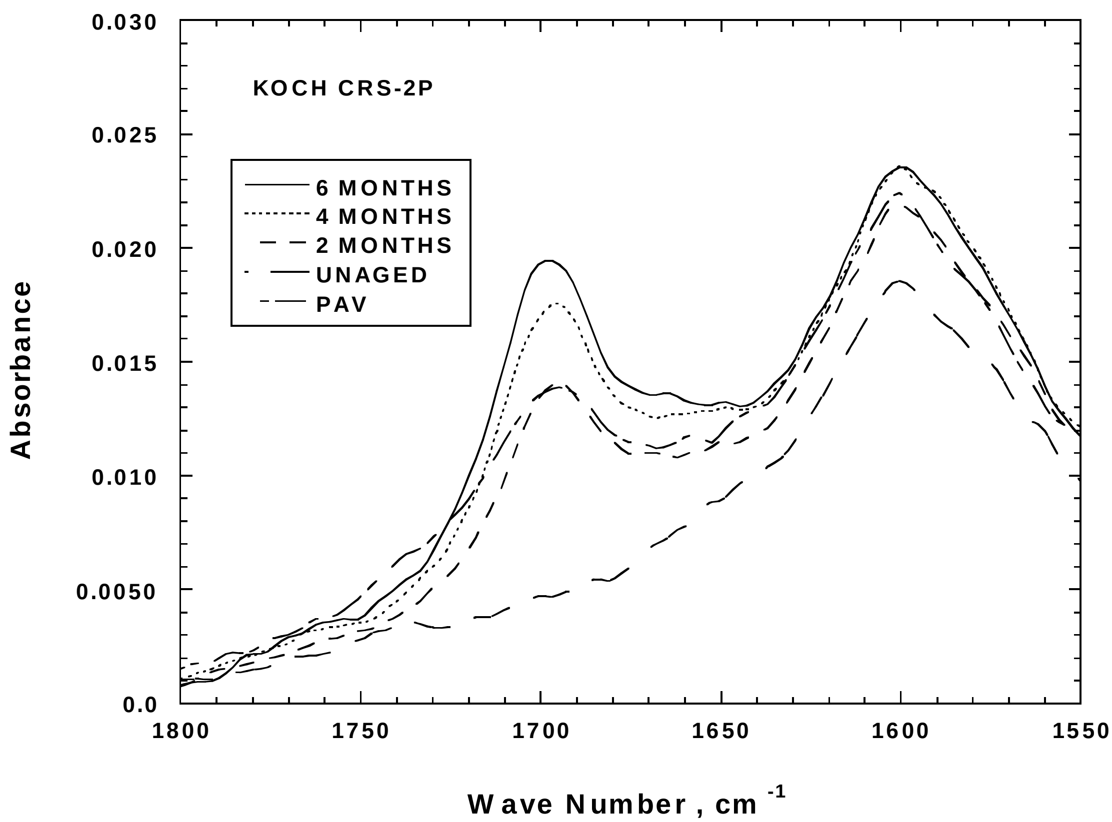


Figure 11. CRS2P Aging in Environmental Room Versus PAV Aging.

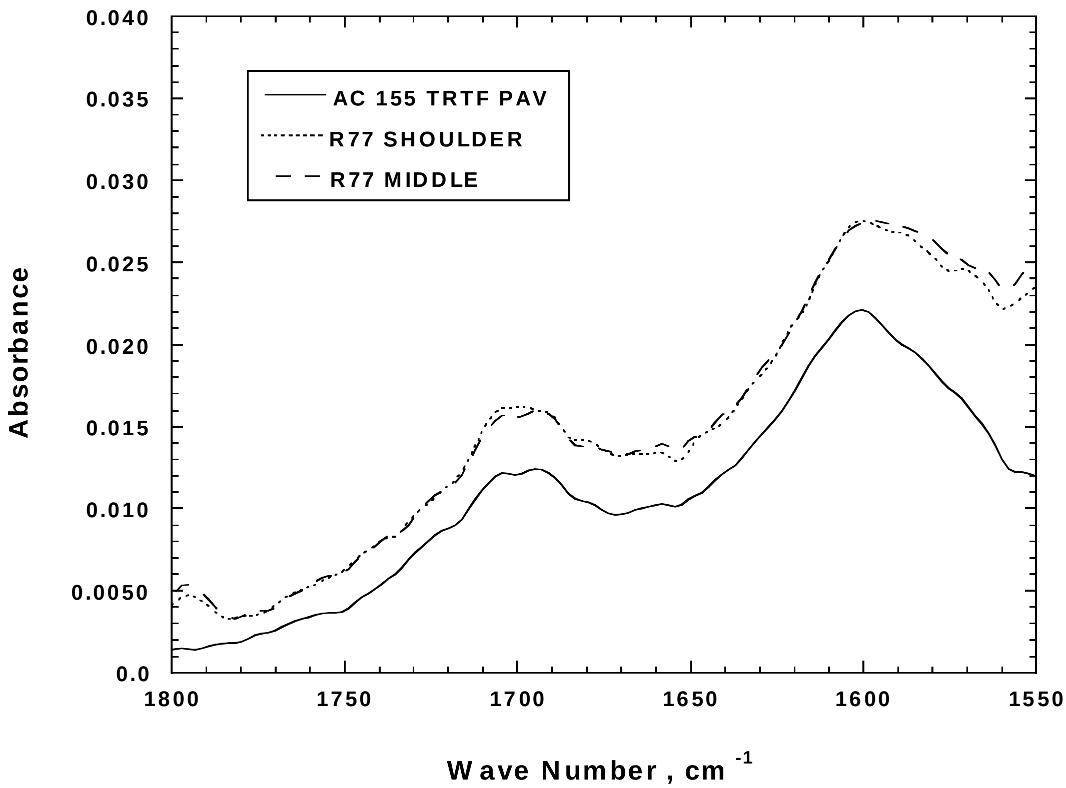


Figure 12. AC15-5TR Aging on Route 77 Versus PAV Aging.

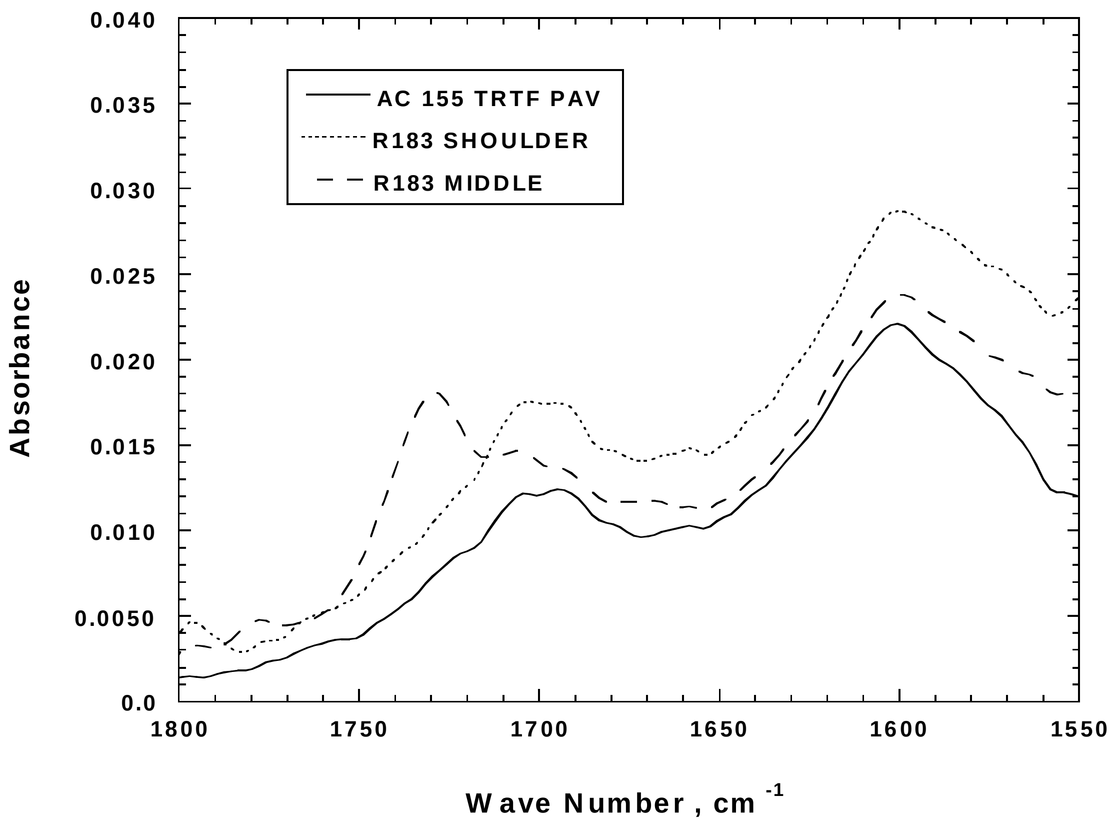


Figure 13. AC15-5TR Aging on Route 183 Versus PAV Aging.

Based on these figures, researchers conclude that aging of a material in the PAV is approximately equivalent to one season of exposure in a surface treatment. They also noted that this same amount of aging was equivalent to approximately two months in the environmental room at 60 °C.

Thus, materials aged only in the PAV did reflect the critical aging condition, and researchers used these materials in the laboratory testing program to represent the critical aging state for low-temperature properties.

Researchers obtained flexural stiffness and m-values measured in the BBR at 8 seconds and at representative low temperatures for material aged only in the PAV. They plotted these values at different temperatures and compared with performance ratings as described in the previous section. Again, they established a threshold value to separate binders that performed well from those that did not. They noted a few exceptions for a relatively uncommon material (HFRS2P), a material whose performance is not governed by low-temperature properties (AC3), and a material commonly applied at low temperatures but that may have exhibited inadequate hardening prior to exposure to high temperatures (CRS1P). All of these exceptions met the recommended specification. The established threshold values for flexural stiffness and m-value were 500 MPa and 0.240, respectively. BBR testing results and the corresponding limiting values at low temperature are shown in Figures 14 and 15.

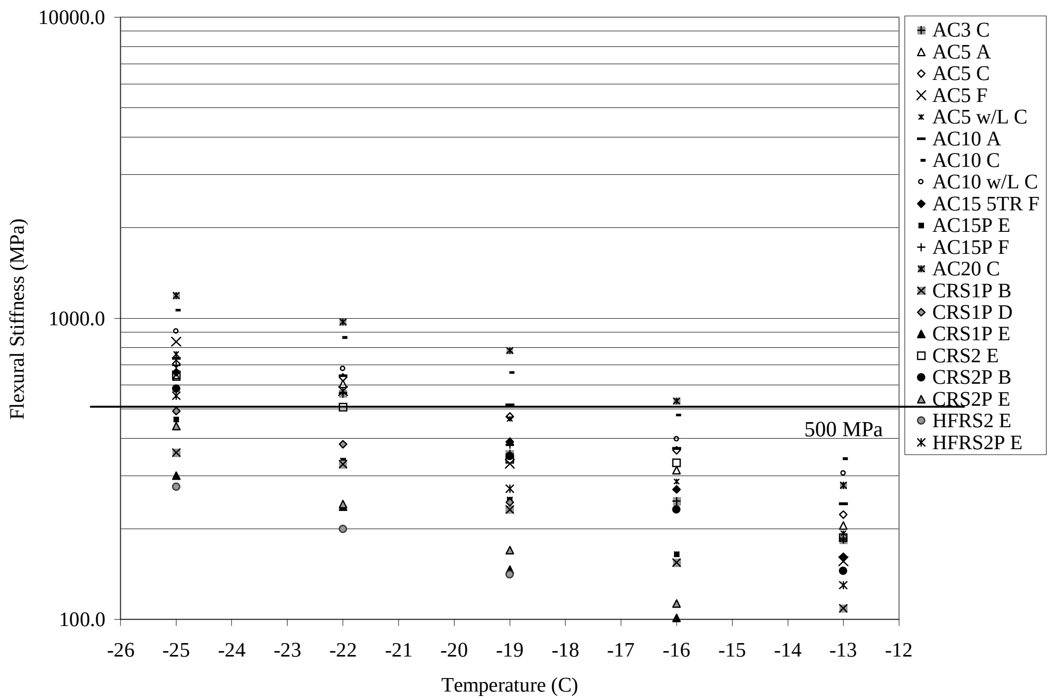


Figure 14. Flexural Stiffness Results and Proposed Limiting Value.

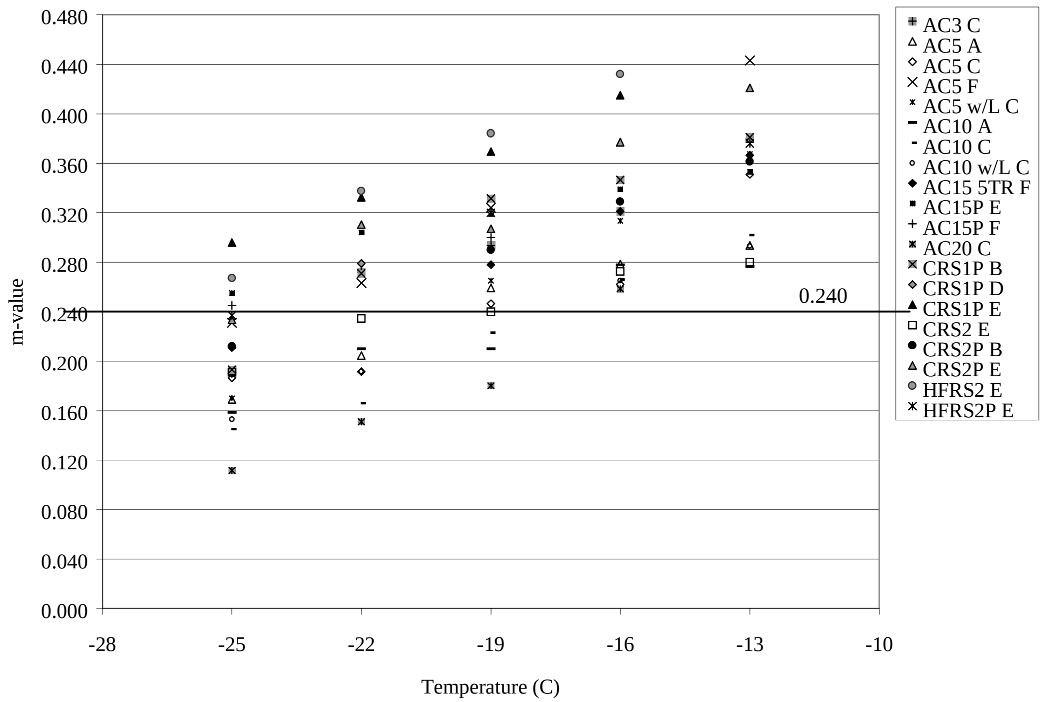


Figure 15. m-value Results and Proposed Limiting Value.

Parallel to the determination of flexural stiffness using BBR results, researchers calculated G* values from RHEA^{TM} software designed by ABATECH, Inc. RHEA^{TM} allows combinations of DSR frequency sweeps and BBR data sets to generate master curves in the frequency domain. They generated plots of G* versus temperature for selected binders aged only in the PAV. They plotted G* values at 17 Hz to represent loading conditions at highway speeds and set a threshold value of 400 MPa for these calculated G* values based on performance ratings and corresponding climate data. Figure 16 presents G* results of selected binders and the established G* limiting value for low temperatures. This threshold correlates with that set for flexural stiffness (500 MPa), again providing a more theoretical basis for the selection of the limiting parameter.

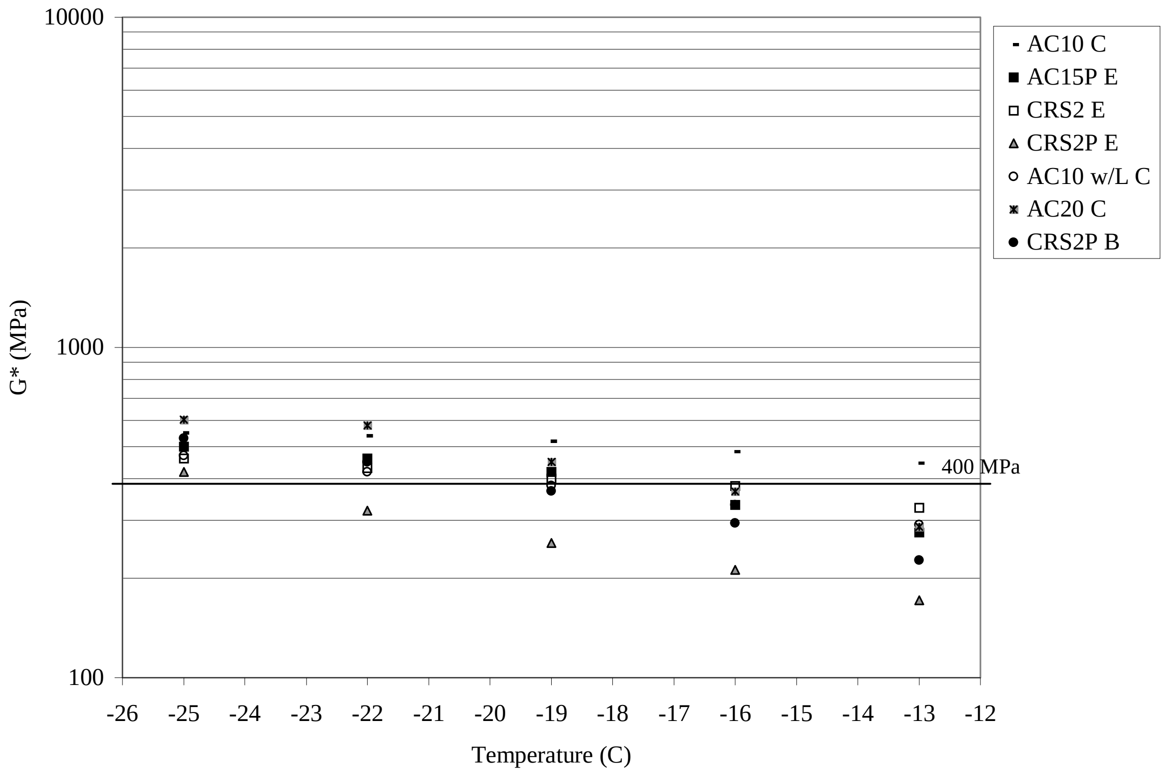


Figure 16. G* Results and Proposed Limiting Value.

Figure 17 depicts the relationship between flexural stiffness (S) and G* values at low temperatures obtained with RHEA™. This figure shows a logarithmic fit for all materials tested, differentiating unmodified and modified binders. Based on this graph, unmodified binders present less scatter than modified binders.

Researchers suggest that the equation in Figure 17 could be used as a provisional equation to estimate G* at low temperatures from BBR results.

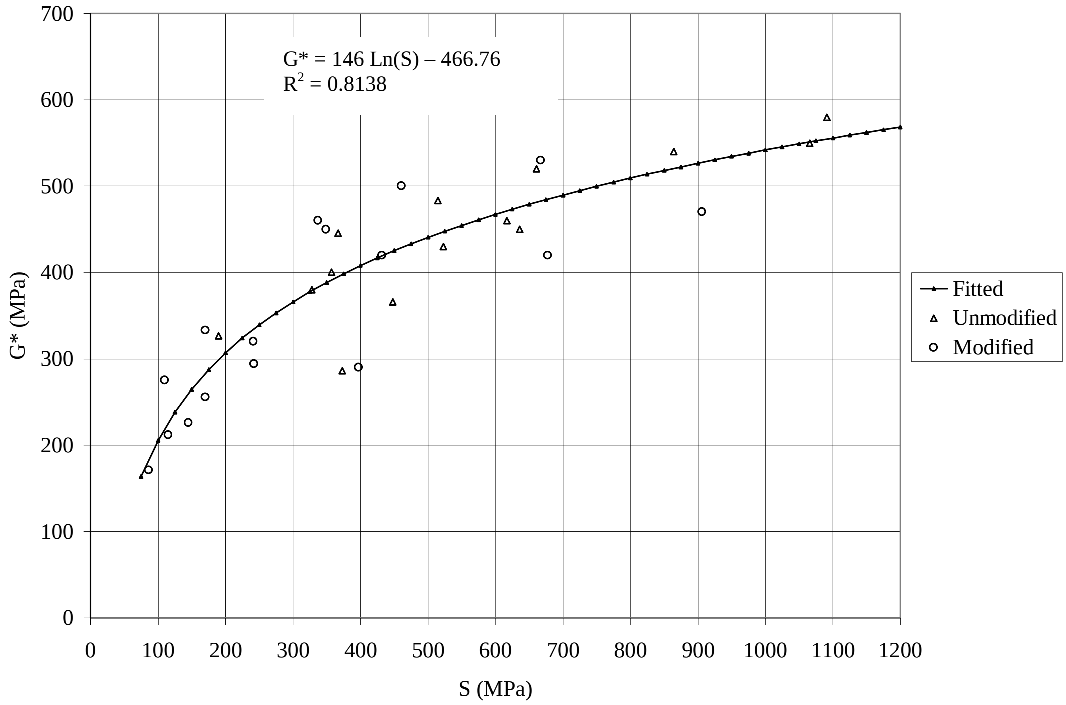


Figure 17. Flexural Stiffness and G* Relationship at Low Temperatures.

CHAPTER 5. SURFACE PERFORMANCE GRADING SPECIFICATION

Table 9 summarizes final recommended values for the SPG performance grading system for surface treatment binders. This 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 °C increments.

Table 9. Recommended Surface Performance Grading.

Performance Grade	SPG 58				SPG 61					SPG 64				
	-16	-19	-22	-25	-13	-16	-19	-22	-25	-13	-16	-19	-22	-25
Avg. 7-day Maximum Surface Pavement Design Temp., °C	<58				<61					<64				
Minimum Surface Pavement Design Temp, °C	>-16	>-19	>-22	>-25	>-13	>-16	>-19	>-22	>-25	>-13	>-16	>-19	>-22	>-25
Original Binder														
Viscosity ASTM D 4402 Max: 0.15; Min: 0.1 Pas Test Temp., °C	<180				<180					<180				
DSR TP5 G*/Sin δ, Min: 0.750 kPa Test Temp. @ 10 rad/s, °C	58				61					64				
PAV Residue (PP1)														
PAV Aging Temp., °C	90				100					100				
Creep Stiffness, TP1 S, Max: 500 MPa m-value, Min: 0.240 Test Temp., @ 8 s, °C	-16	-19	-22	-25	-13	-16	-19	-22	-25	-13	-16	-19	-22	-25

GRADING RESULTS

Researchers determined high and low performance temperatures based on laboratory testing results at multiple temperatures and recommended limiting values, and they assigned SPG grades to all selected binders based on Table 9. Table 10 summarizes standard PG grades, PG grades based on pavement surface temperatures, and SPG grades.

Table 10. Standard PG and SPG Grades.

Binder	Supplier	Standard PG	Standard Surface PG	Modified SPG
Emulsions				
CRS1P	B	52 - 28	52 - 28	58 - 22
CRS1P	D	52 - 28	52 - 28	52 - 22
CRS1P	E	52 - 28	52 - 28	58 - 28
CRS2	E	52 - 28	52 - 28	58 - 19
CRS2P	B	58 - 28	58 - 28	67 - 22
CRS2P	E	58 - 28	58 - 28	70 - 25
HFRS2	E	52 - 28	52 - 28	61 - 25
HFRS2P	E	64 - 28	64 - 28	70 - 22
Asphalt Cements				
AC1.5	C	xx - 34	xx - 34	xx - xx
AC3	C	xx - 28	xx - 28	49 - 19
AC5	A	46 - 28	46 - 28	58 - 19
AC5	C	52 - 28	52 - 28	55 - 19
AC5	F	52 - 28	52 - 28	55 - 19
AC5w/L	C	52 - 28	52 - 28	58 - 19
AC10	A	52 - 22	52 - 22	61 - 16
AC10	C	52 - 22	52 - 22	61 - 16
AC10w/L	C	52 - 22	52 - 22	64 - 16
AC15P	E	52 - 34	52 - 34	67 - 25
AC15P	F	58 - 28	58 - 28	67 - 19
AC15-5TR	F	58 - 28	58 - 28	67 - 19
AC20	C	58 - 22	58 - 22	64 - 16

Note: xx No grade was determined for these binders

Based on Table 10, PG grades based on pavement surface temperatures do not reflect any changes from the standard PG grades due to the 6 °C increment rounding practice. The SPG low-temperature grades are warmer than those obtained with the standard PG grading system, especially for asphalt cements. In general, this 3 °C increment practice makes the SPG grading system more efficient and focuses the climatic range where each binder is likely to perform adequately.

With the standard PG high-temperature grade as reference, modified binders showed a greater increase in the SPG high-temperature grade compared to unmodified binders. When comparing CRS2P and CRS2 from supplier E, the SPG system registered an improvement of four grades in the high-temperature grade and two in the low-temperature grade (Figure 18). The effect of latex for similar base asphalt cements (AC5 and AC10 with and without latex) only increased the high-temperature grade by one and did not have any effect on the low-temperature grade.

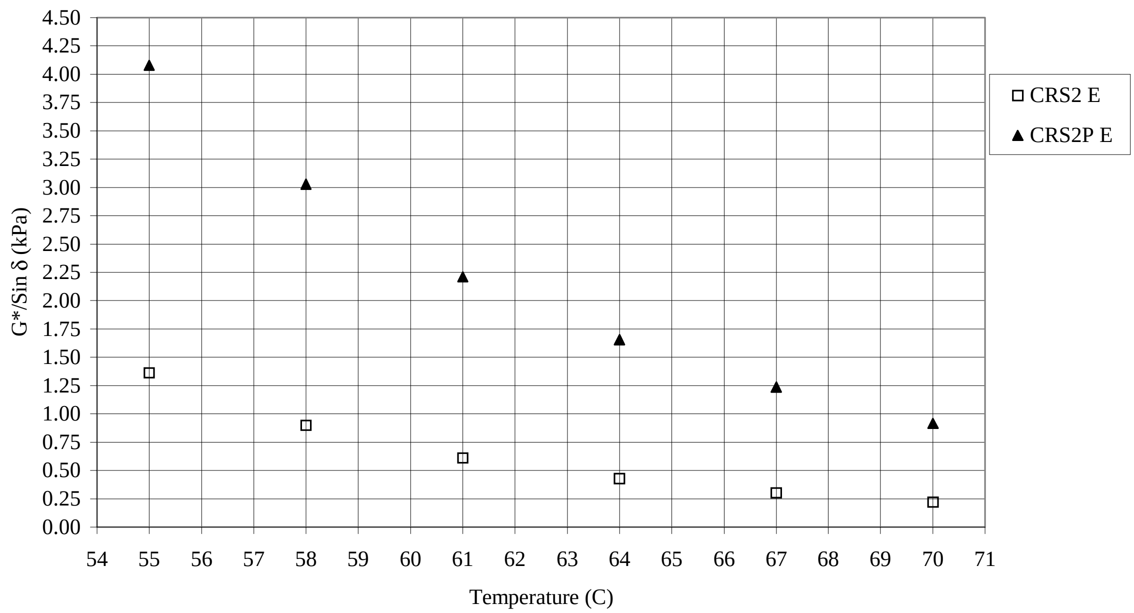


Figure 18. CRS2 E and CRS2P E DSR Results.

GRADE SELECTION PROCESS

The climate in which the pavement is placed determines selection of the PG binder grade *(6)*. The same criterion applies for SPG binders. The selection of a specific SPG binder depends on the minimum and maximum pavement surface temperatures of the zone or region where the binder will be used.

To select a SPG binder, researchers or practitioners evaluate available climate data to determine the hottest 7-day period and the 1-day minimum air temperature for each year. They calculate mean and standard deviation of all the years of record to establish a level of reliability in binder selection as described subsequently. Since the SPG design temperatures are based on surface pavement temperatures, they utilize equations (1) and (3) for the high design temperature and low design temperature, respectively, to transform air temperatures to surface pavement temperatures.

Researchers designed the SPG system to assign a degree of risk to the high and low design temperatures used in selecting the binder grade just like the Superpave PG grading system does. Reliability is defined in this case as a percent probability in a single year that the actual temperature (1-day low or 7-day high) will not exceed the design temperatures *(6)*. The level of reliability is assigned using equations (2) and (4) for high and low design temperatures, respectively. The z-value is obtained from tables for the standard normal distribution ($\mu = 0$ and $\sigma = 1$). Normally, researchers or practitioners use 50 or 98 percent reliability to establish the design temperature of a project, where 50 percent means that there is a 50 percent chance that the air temperature will exceed the expected value and 98 percent that there is only a 2 percent chance that this event will occur. The use of a higher reliability level for selecting binders in the SPG system increases the probability of good surface treatment performance.

Table 11 presents an example to illustrate the SPG grade selection process assuming the available 35-year climate 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 º. Table 11 presents the calculations for the determination of the pavement surface temperatures and the 50 and 98 percent reliability final SPG grade. Information presented in Table 11 also shows the effect of the 3 °C increment rounding and the reliability level in the grade selection of a binder for a given project.

Table 11. Example of the SPG Grade Selection Process.

Reliability Level (%)	High Pavement Surface Temperature (1) (°C)	Low Pavement Surface Temperature (3) (°C)	High-Low Surface Temperature (°C)
-	$T_{surf} - T_{air} = -0.00618\ lat^2 + 0.2289\ lat + 24.4 = 33.98$ $T_{surf} = 33.98 + T_{air} = 33.98 + 29 = 62.98$	$T_{surf} = T_{air} = -18$	63-18
-	High Design Temperature (2) (°C)	Low Design Temperature (4) (°C)	Final SPG Grade Selection (°C)
50	$T_{pav} = T_{surf} + z \times S_{air} = 62.98 + 0 * 1.64 = 62.98$	$T_{pav} = T_{air} - z \times S_{air} = -18 – 0 * 2.5 = -18$	64-18
98	$T_{pav} = T_{surf} + z \times S_{air} = 62.98 + 2.06 * 1.64 = 66.35$	$T_{pav} = T_{air} - z \times S_{air} = -18 – 2.06 * 2.5 = - 23.15$	67-25

Note: - Not Applicable

CHAPTER 6. FIELD VALIDATION EXPERIMENT

Researchers recognized that a field experiment must be completed to validate the recommended SPG specification. This section presents a recommended design of the validation experiment that includes identification of appropriate projects considering the use of common asphalt cements and emulsions under different climate and loading conditions, performance monitoring, and general evaluation of the SPG specification.

PROJECT IDENTIFICATION

Researchers must evaluate surface treatment projects in Texas districts to determine whether they are suitable for inclusion in the field validation experiment. They recommend obtaining samples of at least two asphalt cements and two emulsions for each of two aggregate types that were used on projects placed under two different environmental conditions and under two levels of traffic. Preferably, future researchers will select unmodified and corresponding modified binders for each material type because modified materials may be more sensitive to the selected factors. With these variables, current researchers suggest a full factorial design for two separate experiments (one for asphalt cements and one for emulsions) to estimate all main effects and two-way interactions. Table 12 presents an example of the experimental design for asphalt cements with two suppliers and a response variable (SCI) defined subsequently.

Table 12 shows a limited number of suppliers to minimize any effects of differences in production methods between suppliers. If future researchers introduce more suppliers, the level of effort to complete the field validation experiment will substantially increase.

Additionally, general information about the surface treatment projects should include the following:

- General information
    - location (highway number, length of section, and milepost),
    - date of construction,
    - condition of the existing pavement or base course, and
    - surface treatment design method.

Table 12. Experimental Design for Asphalt Cements.

Binder	Supplier (S)	Environment (E)	Traffic (T)	Aggregate (A)	Modifier	SCI
	S 1	E 2	T 2	A 1	M	-
	S 1	E 1	T 1	A 2	U	-
	S 1	E 1	T 2	A 2	M	-
	S 1	E 2	T 1	A 2	M	-
	S 1	E 1	T 1	A 1	M	-
	S 1	E 2	T 2	A 2	U	-
	S 1	E 1	T 2	A 1	U	-
	S 1	E 2	T 1	A 1	U	-
	S 2	E 2	T 2	A 1	U	-
	S 2	E 1	T 2	A 1	M	-
	S 2	E 1	T 1	A 2	M	-
	S 2	E 2	T 2	A 2	M	-
	S 2	E 2	T 1	A 2	U	-
	S 2	E 1	T 1	A 1	U	-
	S 2	E 2	T 1	A 1	M	-
	S 2	E 1	T 2	A 2	U	-

- Materials
    - Binder
        - binder type and supplier, and
        - binder application rate.
    - Aggregate
        - aggregate type (limestone, gravel, lightweight, etc.),
        - gradation,
        - shape, and
        - aggregate application rate.
- Construction
    - traffic control (one lane at a time, both lanes, no traffic, etc.),
    - breaking time (for emulsions),
    - type of rolling, and
    - special situations (rain, oil spills, delays, etc.),
- Traffic
    - average daily traffic and traffic composition.

MONITORING PROGRAM

Researchers recognize that a visual survey of the selected projects must be performed to try to validate the results of the SPG specification. The recommended methodology presented here is an adaptation of a procedure used in the state of Wyoming and other systems used to evaluate surface treatments *(20, 12)*.

The general procedure of the monitoring program for this validation experiment consists of three main steps. First, researchers divide road sections into 2476 ft^2 ± 9690 ft^2 (230 ± 90 m^2) areas called units. Second, they measure and evaluate distress related only to surface treatments. Finally, they determine a surface condition index (SCI) based on the distress observed in the second step.

Sample Selection

It is appropriate to inspect the entire section of the project for the monitoring program. However, this task may take too much time and effort. Instead, researchers may survey representative units of sections. Current researchers suggest dividing projects into consecutively numbered units (2476 ft^2 ± 9690 ft^2 (230 ± 90 m^2) areas) and then randomly selecting the units to be monitored (six or eight sample units per project) *(12)*.

Distress Measurement

Distress identification, measurement, and evaluation are critical aspects for the success of the validation of the SPG specification. Researchers recognize that it is important to distinguish the distresses related to surface treatment performance from those related to HMAC. They consider aggregate loss, bleeding, and longitudinal and transverse cracking the primary distresses related to surface treatment performance, and they suggest their inclusion in the monitoring program. An additional indicator of surface treatment performance is aggregate embedment.

Future researchers will evaluate a sample unit by marking the end points of the sample unit on a paper and then sketching the length and severity of the distresses *(12)*. The distress evaluation of the surface treatment project is the summation of each distress type found in each sample unit divided by the total area of the six or eight sample units randomly selected. They will also report aggregate embedment as the average of the sample units results.

SCI Calculation

The SCI is a rating system with a scale of 100 to 0, where 100 is a perfect score. The SCI consists of four distress types with arbitrary weights assigned to each distress. Researchers subdivide distress categories into two parts to account for the percentage area covered by the distress and the severity level. Currently, the same weights are shown for each subdivision. Table 13 presents the components and weights of the SCI rating system.

For this proposed SCI system, researchers recommend tentative threshold values for good (SCI ≥ 75), fair (55 ≥ SCI < 75), and poor (SCI < 55) surface treatment performance. They also suggest revisions of the threshold values and distress weights to accurately reflect TxDOT's priorities.

General Evaluation

Researchers recommend five evaluations for this particular validation experiment: immediately after construction, before and after the first winter, and during the subsequent spring and summer seasons. After completion of the monitoring program, researchers suggest comparing survey results and the SPG specification and design temperatures to establish the validity of the SPG. Comparisons to identify characteristics of good performing and failing surface treatments must also include DSR results and FTIR analysis of field samples from surveyed projects.

Table 13. SCI Components and Weights.

Distress Type			SCI	Comments
Aggregate Loss				
Subdivision		Weight		
% Area	Weight	0.35		
100 50 10 0 (% area) 0 30 70 100 (SCI points)	0.50			
Severity Level	Weight			
Sev Mod Slt (severity level) 0 30 70 100 (SCI points)	0.50			
Bleeding				
Subdivision		Weight		
% Area	Weight	0.25		
100 50 10 0 (% area) 0 30 70 100 (SCI points)	0.50			
Severity Level	Weight			
Sev Mod Slt (severity level) 0 30 70 100 (SCI points)	0.50			
Longitudinal Cracking				
Subdivision		Weight		
% Area	Weight	0.20		
100 50 10 0 (% area) 0 30 70 100 (SCI points)	0.50			
Severity Level	Weight			
Sev Mod Slt (severity level) 0 30 70 100 (SCI points)	0.50			
Transverse Cracking				
Subdivision		Weight		
% Area	Weight	0.20		
100 50 10 0 (% area) 0 30 70 100 (SCI points)	0.50			
Severity Level	Weight			
Sev Mod Slt (severity level) 0 30 70 100 (SCI points)	0.50			
Final SCI (summation of all SCI points multiplied by corresponding weights)				Aggregate Embedment (%)

Note: Sev = severe, Mod = moderate, Slt = Slight

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

Researchers developed the SPG specification using existing Superpave equipment to measure physical properties of binders that account for common distresses observed in surface treatments. They used representative temperatures in Texas and binder performance ratings to establish limiting values for the required properties for determination of SPG high- and low-temperature grades. They further validated these limiting values based on more theoretical approaches. Parameters in the SPG specification consider critical aging and loading to reflect conditions in the field.

Researchers made the following two recommendations to ensure the success of the SPG specification and associated grade selection process:

- Future researchers need to complement performance-based binder specification through the development of new and simpler testing equipment and a methodology to directly obtain G* at low temperatures.
- Future researchers should also consider evaluation of the possible adjustment of grades in the SPG grade selection process due to traffic and loading conditions based on a review of the recommended validation experiment results.

Since the Modified Performance Grading is based on fundamental physical properties related to field performance, researchers expect the SPG specification will be useful in grading and selecting surface treatment binders to assure good performance. The SPG specification is also relatively simple and economical to implement because it is based on the widely implemented PG equipment and grading system.

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APPENDIX A EVALUATION SURVEYS

TxDOT

A performance graded (PG) binder specification has been developed and implemented by TxDOT in Hot Mix Asphalt Concrete projects. These specifications are not directly valid for surface treatment binders. The purpose of this study is to develop an analogous specification system. This survey is the first task towards accomplishing the goal of this project. Please answer the following questions:

Name: ____ Date: _____________
Company/ District _________________________ Title: ___________________________
Phone: _____________ Fax: ____________ e-mail: ____________________________

I. - What kind of asphalt binder/ emulsion has your district used in **surface treatments**?

Binder:	Modified?	Modifier/Emulsifying Agent	Performance
#1. - _________________	[] Yes [] No	____________________	[] Good [] Fair [] Bad
#2. - _________________	[] Yes [] No	____________________	[] Good [] Fair [] Bad
#3. - _________________	[] Yes [] No	____________________	[] Good [] Fair [] Bad
#4. - _________________	[] Yes [] No	____________________	[] Good [] Fair [] Bad
#5. - _________________	[] Yes [] No	____________________	[] Good [] Fair [] Bad

Reasons for binder modification? ____

***** Suggest (either based on [] opinion or [] experience) binders that show poor performance in surface treatments.
____

II. – Please check box (es) and complete the following table referring to the binder number of question I. (If necessary make copies of the table below).

		BINDER # ___	**BINDER # ___**	**BINDER # ___**
BINDER	Provider	[] Koch Materials [] Texas Fuel [] Coastal [] Wright Asphalt []___________ [] Fina [] Texaco [] Gulf State [] Chevron [] Exxon	[] Koch Materials [] Texas Fuel [] Coastal [] Wright Asphalt []___________ [] Fina [] Texaco [] Gulf State [] Chevron [] Exxon	[] Koch Materials [] Texas Fuel [] Coastal [] Wright Asphalt []___________ [] Fina [] Texaco [] Gulf State [] Chevron [] Exxon
SURFACE TREATMENT	Design	Design method for the chip seal: [] Experience [] Modified Kearby [] Other ____________ Design life ___________ years Design life Versus actual life? [] Good [] Fair [] Bad	Design method for the chip seal: [] Experience [] Modified Kearby [] Other ____________ Design life ___________ years Design life Versus actual life? [] Good [] Fair [] Bad	Design method for the chip seal: [] Experience [] Modified Kearby [] Other ____________ Design life ___________ years Design life Versus actual life? [] Good [] Fair [] Bad
	Existing Pavement	Condition of existing pavement: [] Dry or raveled surface [] Bleeding surface [] Water infiltration [] Alligator cracking [] Rutting [] Other ______________	Condition of existing pavement: [] Dry or raveled surface [] Bleeding surface [] Water infiltration [] Alligator cracking [] Rutting [] Other ______________	Condition of existing pavement: [] Dry or raveled surface [] Bleeding surface [] Water infiltration [] Alligator cracking [] Rutting [] Other ______________
AGGREGATES	TYPE Tx DOT item 302	❑ Type A ❑ Type B ❑ Type C ❑ Type D ❑ Type E ❑ Type PA ❑ Type PB ❑ Type PC ❑ Type PD ❑ Type PE	❑ Type A ❑ Type B ❑ Type C ❑ Type D ❑ Type E ❑ Type PA ❑ Type PB ❑ Type PC ❑ Type PD ❑ Type PE	❑ Type A ❑ Type B ❑ Type C ❑ Type D ❑ Type E ❑ Type PA ❑ Type PB ❑ Type PC ❑ Type PD ❑ Type PE
	SHAPE	❑ Cubical ❑ Rounded ❑ Subrounded ❑ Flat and elongated ❑ Other… Which? _________	❑ Cubical ❑ Rounded ❑ Subrounded ❑ Flat and elongated ❑ Other… Which? _________	❑ Cubical ❑ Rounded ❑ Subrounded ❑ Flat and elongated ❑ Other… Which? _________
	GRADATION Tx DOT item 302	❑ Grade 3 ❑ Grade 4 ❑ Grade 5 ❑ One Size... __________ ❑ Other________________	❑ Grade 3 ❑ Grade 4 ❑ Grade 5 ❑ One Size... __________ ❑ Other________________	❑ Grade 3 ❑ Grade 4 ❑ Grade 5 ❑ One Size... __________ ❑ Other________________

		BINDER # __	BINDER # __	BINDER # __
CRITERIA FOR MATERIAL SELECTION	BINDER	______________________ ______________________ ______________________ ______________________ ______________________ ______________________ ____________________	______________________ ______________________ ______________________ ______________________ ______________________ ______________________ ____________________	______________________ ______________________ ______________________ ______________________ ______________________ ______________________ ____________________
	AGGREGATE	______________________ ______________________ ______________________ ______________________ ______________________ ______________________ ____________________	______________________ ______________________ ______________________ ______________________ ______________________ ______________________ ____________________	______________________ ______________________ ______________________ ______________________ ______________________ ______________________ ____________________
TRAFFIC AREAS (Vehicles per lane per day)		❑ High (>4000) ❑ Med. (2500-4000) ❑ Low (< 2500) ❑ Turn/Accelerating zones Were any of these conditions considered in the design? [] Yes [] No How? ___________________ _______________________	❑ High (>4000) ❑ Med. (2500-4000) ❑ Low (< 2500) ❑ Turn/Accelerating zones Were any of these conditions considered in the design? [] Yes [] No How? ___________________ _______________________	❑ High (>4000) ❑ Med. (2500-4000) ❑ Low (< 2500) ❑ Turn/Accelerating zones Were any of these conditions considered in the design? [] Yes [] No How? ___________________
MAIN DISTRESSES SHOWN		**A**.- [] Bleeding **B**.- [] Aggregate loss **C**.- [] Streaking **D**.- [] Other______________ **E**.- [] Other ______________ **F**.- [] None Comments______________________ ______________________________ ______________________________	A.- [] Bleeding B.- [] Aggregate loss C.- [] Streaking D.- [] Other______________ E.- [] Other ______________ F.- [] None Comments______________________ ______________________________ ______________________________	A.- [] Bleeding B.- [] Aggregate loss C.- [] Streaking D.- [] Other______________ E.- [] Other ______________ F.- [] None Comments______________________ ______________________________ ______________________________
POSSIBLE CAUSES OF DISTRESSES (relate to the distresses above)		**Distress: A B C D E** **Design** [ ] [ ] [ ] [ ] [ ] [] Binder application rate [] Aggregate application rate **Construction** [ ] [ ] [ ] [ ] [ ] [] Pavement preparation [] Time delay binder-aggregate [] Traffic control [] Workmanship [] Equipment (spraying, rolling) **Weather.** [ ] [ ] [ ] [ ] [ ] [] Rainy or wet surface [] Hot temperature [] Cold temperature **Mat. Selec.** [ ] [ ] [ ] [ ] [ ] [] Improper binder [] Wet aggregate [] Dusty aggregate [] Aggregate size [] Binder & agg. incompatibility [] Agg. toughness & durability Other_____________________ Explain __________________ __________________________	**Distress: A B C D E** **Design** [ ] [ ] [ ] [ ] [ ] [] Binder application rate [] Aggregate application rate **Construction** [ ] [ ] [ ] [ ] [ ] [] Pavement preparation [] Time delay binder-aggregate [] Traffic control [] Workmanship [] Equipment (spraying, rolling) **Weather.** [ ] [ ] [ ] [ ] [ ] [] Rainy or wet surface [] Hot temperature [] Cold temperature **Mat. Selec.** [ ] [ ] [ ] [ ] [ ] [] Improper binder [] Wet aggregate [] Dusty aggregate [] Aggregate size [] Binder & agg. incompatibility [] Agg. toughness & durability Other_____________________ Explain __________________ __________________________	**Distress: A B C D E** **Design** [ ] [ ] [ ] [ ] [ ] [] Binder application rate [] Aggregate application rate **Construction** [ ] [ ] [ ] [ ] [ ] [] Pavement preparation [] Time delay binder-aggregate [] Traffic control [] Workmanship [] Equipment (spraying, rolling) **Weather.** [ ] [ ] [ ] [ ] [ ] [] Rainy or wet surface [] Hot temperature [] Cold temperature **Mat. Selec.** [ ] [ ] [ ] [ ] [ ] [] Improper binder [] Wet aggregate [] Dusty aggregate [] Aggregate size [] Binder & agg. incompatibility [] Agg. toughness & durability Other_____________________ Explain __________________ __________________________

		BINDER # __	BINDER # __	BINDER # __
EVALUATION		Poor Good	Poor Good	Poor Good
	Water Sealing	(0) (1) (2) (3) (4) (5)	(0) (1) (2) (3) (4) (5)	(0) (1) (2) (3) (4) (5)
	Skid Resist.	(0) (1) (2) (3) (4) (5)	(0) (1) (2) (3) (4) (5)	(0) (1) (2) (3) (4) (5)
	Tire noise	(0) (1) (2) (3) (4) (5)	(0) (1) (2) (3) (4) (5)	(0) (1) (2) (3) (4) (5)
	Appearance	(0) (1) (2) (3) (4) (5)	(0) (1) (2) (3) (4) (5)	(0) (1) (2) (3) (4) (5)
	Agg. retention	(0) (1) (2) (3) (4) (5)	(0) (1) (2) (3) (4) (5)	(0) (1) (2) (3) (4) (5)
	Overall performance	(0) (1) (2) (3) (4) (5)	(0) (1) (2) (3) (4) (5)	(0) (1) (2) (3) (4) (5)
	Cost-effective	(0) (1) (2) (3) (4) (5)	(0) (1) (2) (3) (4) (5)	(0) (1) (2) (3) (4) (5)

Do you have a specific program to evaluate surface treatments? [] Yes [] No

Surface treatment season? Start_______________ End __________________

Please add any comments or recommendations with respect to improving the overall performance of surface treatments, especially with regard to binder properties and selection for surface treatment applications.

Thank you for your time and effort spent in completing this survey. We plan to use this information to develop an improved specification for binders used in surface treatments.

Outside Experts & Contractors

A performance graded (PG) binder specification has been developed and implemented by TxDOT in Hot Mix Asphalt Concrete projects. These specifications are not directly valid for surface treatment binders. The purpose of this study is to develop an analogous specification system. This survey is the first task towards accomplishing the goal of this project. Please answer the following questions:

Name: ____ Date: _______________
Company/ District ____________________________ Title: ______________________________
Phone: _______________ Fax: ______________ e-mail: _______________________________

TxDOT definition of **surface treatment**: a single, double, or triple application of either hot asphalt cement materials, asphalt emulsions, or cutback asphalts, each covered with aggregate. These surface treatments are constructed on existing pavements or on a prepared base coarse. These asphalt applications are also commonly called **seal coats or chip seals**.

In your personal opinion, what defines good performance for a surface treatment?
____
____
____

In your experience, what asphalt binders/emulsions have performed well in surface treatments?
____
____
____

In your experience, what asphalt binders/emulsions have shown poor performance in surface treatments?
____
____
____

In what situations do you recommend the use of modified binders? (e.g. weather, existing paving condition, etc.) Please mention modifier and particular situation.
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____
____
____

In your opinion, what laboratory tests might be used to predict the field performance of the binder in a surface treatment?
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____
____

What aggregate gradation is best for surface treatments?
____
____
____

Do you recommend the use of pre-coated aggregate? If so, under what circumstances?
____
____
____

What design methods for surface treatments are you familiar with? What are the main design parameters in each method?
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____
____

In your experience with a particular design method, what were the criteria for binder selection?

____
____
____

Does each particular design method you are familiar with account for existing paving condition, traffic levels, turn/acceleration zones, etc.? How?

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____
____

What are the advantages and disadvantages of using a hot applied asphalt cement in a surface treatment?

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____
____

What are the advantages and disadvantages of using an emulsion in a surface treatment?

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____
____

When would you recommend an emulsion over a hot applied asphalt cement and vice versa?

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____
____

What design parameter most affects the performance of the surface treatment? (e.g. binder selection, aggregate selection, binder-aggregate ratio, construction, etc.)

____
____
____

In your experience, what is the average design life for a surface treatment?

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____
____
____
____

What distresses are more likely to be observed in a surface treatment? What is the main cause in your opinion?

____
____
____

How would you prevent the identified distresses?

____
____
____
____

On a 1 to 3 scale (3 very common), how would you rate the following distresses.

Bleeding	( )
Streaking	( )
Aggregate loss	( )
Reflection cracking	( )
Other_____________	( )
Other_____________	( )

What are the ideal weather and temperature conditions for the placement of a surface treatment?
____
____
____

On a 1 to 5 scale (5 very important), how would you rate the following regarding the effect on surface treatment performance.

Pavement preparation	( )
Time delay binder-aggregate	( )
Traffic control	( )
Workmanship	( )
Spraying	( )
Rolling	( )

What is your suggested time to wait before opening a section to traffic after application of a surface treatment?
____
____
____

Please add any comments or recommendations with respect to improving the overall performance of surface treatments, especially with regard to binder properties and selection for surface treatment applications.

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Thank you for your time and effort spent in completing this survey. We plan to use this information to develop an improved specification for binders used in surface treatments.

APPENDIX B EVALUATION SURVEY RESULTS

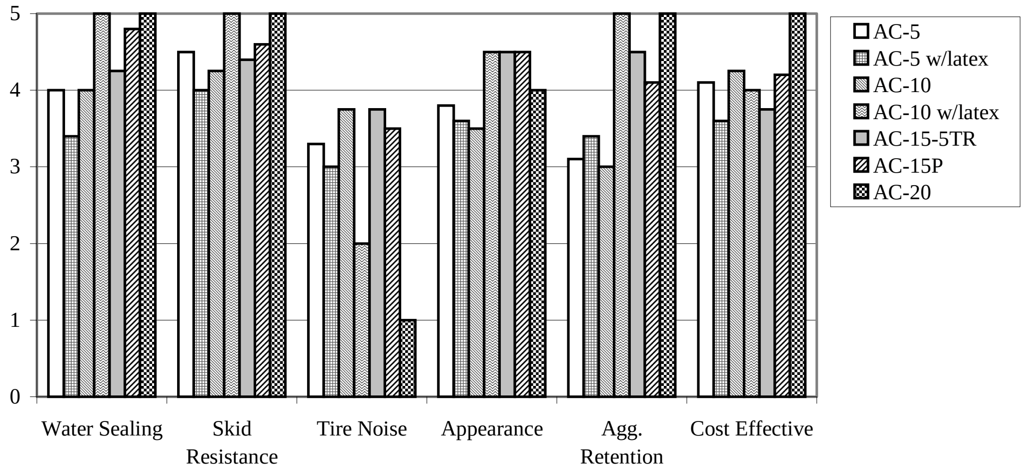

Figure B1 Asphalt Cement Evaluation Results.

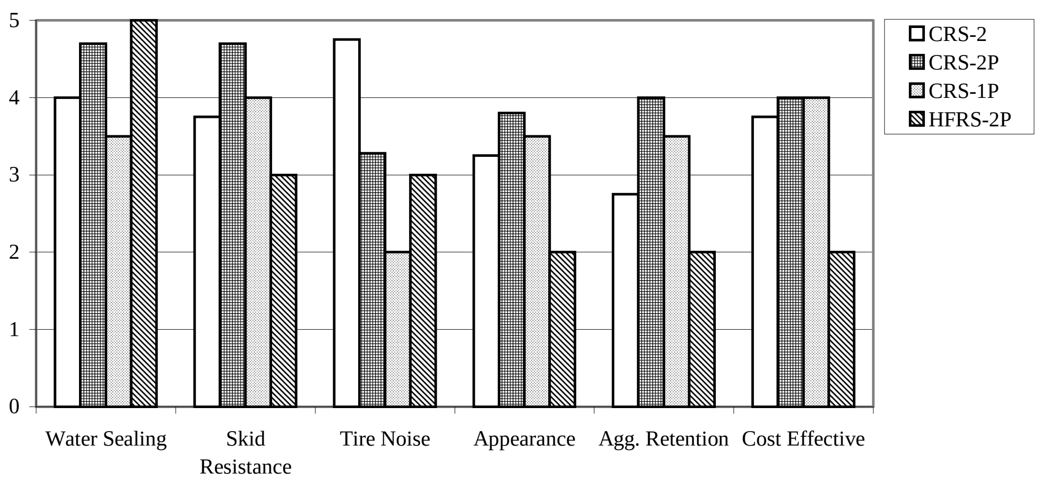

Figure B2 Asphalt Emulsion Evaluation Results.