Evolution of Performance-Graded Specifications for Chip Seal Binders in the United States

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***Synopsis* – Performance-graded (PG) specifications for chip seal binders in service are available in the United States to extend the service life of these common maintenance treatments. Currently, Texas Department of Transportation (TxDOT) Special Provision SP300-018 is available for both hot-applied binders and emulsion residues, and American Association of State Highway Transportation Officials (AASHTO) Provisional Standard MP 37-18 is available for hot-applied binders. The Surface PG (SPG) specification that forms the basis for these standards was developed and validated through both TxDOT research and National Cooperative Highway Research Program (NCHRP) Project 14-17. Subsequently, an Emulsion PG (EPG) specification that focuses only on properties of emulsion residues was developed as part of NCHRP Project 09-50. These specifications are similar to the Superpave PG specifications for paving grade hot mix asphalt binders with respect to the climate-based framework, testing equipment, and performance-based properties. However, they reflect critical distresses including bleeding and aggregate loss, construction practices, and climate conditions that are more applicable to chip seals. SPG and EPG specifications were evaluated by a national task force in a round-robin testing program that resulted in a blended working standard for emulsion residues that determines high-temperature grade using concepts from the SPG specification and low-temperature grade using concepts from the EPG specification. This blended standard formed the starting point for ongoing NCHRP Project 09-63 focused on the development and further field validation of an Emulsified Asphalt Performance Grading (EAPG) system.**

Keywords—chip seal; binder; performance; specification

1. INTRODUCTION

Most highway agencies in the United States (U.S.) have implemented pavement preservation programs to maintain roadway networks and decrease the need for costly repairs and rehabilitation. Surface treatments constitute a critical component of pavement preservation. Surface treatments can improve pavement sustainability by extending the pavement service life while reducing energy consumption and greenhouse gas emissions. Chip seals are among the most effective and commonly used surface treatments. They typically contain a hot-applied asphalt binder or asphalt emulsion that waterproofs and rejuvenates the surface and binds single-size, clean aggregate particles that provide surface friction. Chip seals typically are constructed by spraying a thin layer of binder or emulsion onto an existing roadway followed by a single layer of aggregate that is rolled with pneumatic tires to partially embed and seat the aggregate into the binder.

Current specifications for chip seal binders consider both the properties of the binder during construction and in service but have a few shortcomings in that they are based on properties developed for unmodified binders that are only measured at intermediate and high temperatures and are not tied to critical chip seal distresses including bleeding and aggregate loss. Furthermore, current specifications fail to consider the effects of climate, traffic, and appropriate aging. These shortcomings result in a wide range of materials that can be utilized that may not provide adequate performance to realize pavement preservation goals.

Two performance-graded (PG) specifications for chip seal binders in service have been developed and proposed to address the aforementioned shortcomings while considering these key issues included in current specifications:

- Assurance of modified behavior,
- Assurance of sprayability during construction,
- Resistance to bleeding at high pavement temperatures, and
- Resistance to aggregate loss at low pavement temperatures with aging.

Like the Superpave PG specification for paving grade hot mix asphalt binders, the proposed PG specifications for chip seal binders were based on performance-related properties instead of composition-specific properties. The first specification is the Surface PG (SPG) specification, developed by the Texas A&M Transportation Institute (TTI), and the second is the Emulsion PG (EPG) specification, developed by North Carolina State University (NCSU). Both the SPG and EPG specifications are similar to the Superpave PG specifications with respect to the climate-based framework and required testing equipment, but they reflect critical distresses, construction practices, and climate conditions for chip seals. The SPG and EPG specifications were further evaluated in a round-robin testing program conducted by the AASHTO Transportation System Preservation Technical Services Program (TSP2) Emulsion Task Force (ETF). This evaluation resulted in a blended standard that is currently being further developed and validated in an ongoing national research project. Each of these three efforts are summarized in this paper to describe the evolution of the effort to modernize chip seal binder specifications in the U.S..

2. SURFACE PERFORMANCE-GRADED (SPG) SPECIFICATION

Over the past two decades, TTI developed, validated, and implemented a surface performance-graded (SPG) specification for chip seal binders in service (emulsion residue or hot-applied asphalt cement) [1-7]. Key modifications of the SPG specification, when compared to the PG specification, account for differences in distress, as well as conditions during production, construction, and in-service, and their effect on performance in terms of aggregate loss and bleeding. These modifications of the SPG specification include:

- Use of high and low surface pavement temperatures to reflect representative conditions for chip seals and 6°C increments shifted by 3°C at both high and low temperatures to avoid confusion with typical PG values;
- Removal of the Rolling Thin Film Oven (RTFO) procedure to simulate short-term aging through a hot-mix plant during construction;
- Removal of the intermediate-temperature property from the Dynamic Shear Rheometer (DSR) and low-temperature m-value from the Bending Beam Rheometer (BBR) since these properties were not correlated with field performance of chip seals;
- Use of low-temperature stiffness (S) from the BBR measured at low surface pavement temperature and 8 seconds of loading after Pressure Aging Vessel (PAV) aging to simulate traffic loading during the critical first year of performance (based on chemical analysis of material aged in the field); and
- Added requirement of a maximum phase angle (δ) at continuous high-temperature grade for chip seal binders with useful temperature intervals greater than 86°C to ensure polymer modification.

Two multi-year Texas Department of Transportation (TxDOT) research projects, a subcontract on National Cooperative Highway Research Program (NCHRP) Project 14-17 *(Manual for Emulsion-Based Chip Seals for Pavement Preservation)*, and a five-year TxDOT implementation project totaling more than $1.4 million USD were utilized to develop and validate the performance-related properties in the SPG specification to control bleeding at high temperatures and aggregate loss at low temperatures during the critical first year in service. Validation efforts included visual field performance monitoring of more than 140 field sections located in a wide variety of climates and monitored after construction, after the first winter, at one year, and at two years in some cases. Eight state and national research reports, six journal publications, 45 posters and presentations, a Texas Transportation Researcher article, a video summary report, two quick reference guides for SPG binder selection and specification, and the infographic shown in Fig. 1 were produced as outreach; and two round robin testing programs were conducted with industry. This effort was recognized by peers in the industry at the Transportation Research Board (TRB) with a 2017 Practice Ready Paper Award. The economic impact of improved chip seal binder selection based on the SPG specification was estimated to be at least a 10:1 benefit-to-cost ratio in Texas assuming the life is extended for a small percentage of the chip seals placed in the large statewide program that expends more than $300 million annually.

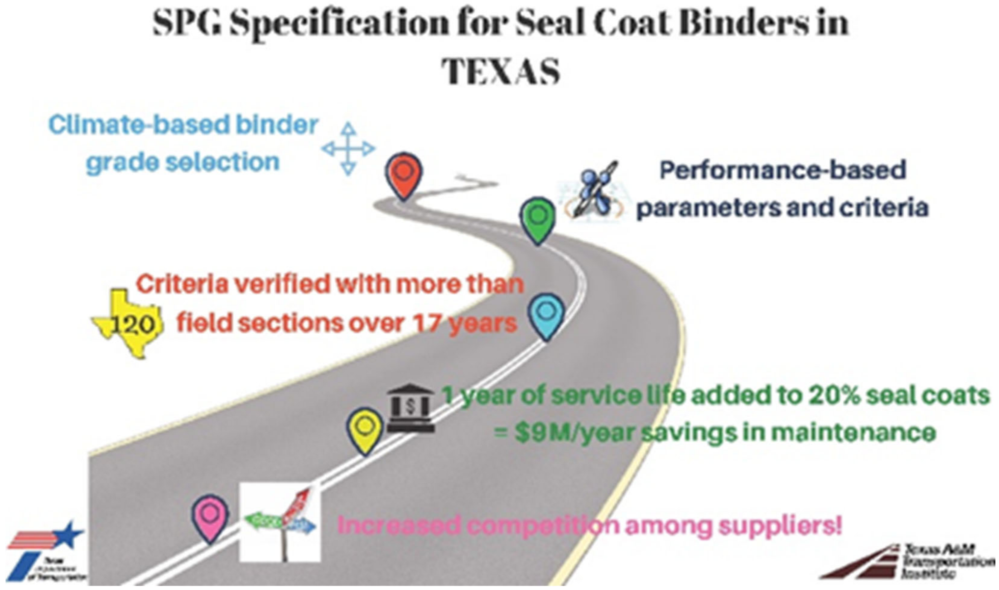

Fig. 1. SPG Infographic.

The SPG specification is now available in Texas as a Special Provision to TxDOT Item 300 (SP300-011) shown in Fig. 2 and is currently approved as AASHTO Provisional Standard MP 37-18 for hot-applied asphalt binders. The SPG framework relies on the Rotational Viscometer (RV), DSR, BBR, and PAV equipment also utilized in AASHTO M 320 and M 332 for paving grade hot mix asphalt binders, with emulsion residues recovered following AASHTO R 78 Procedure B.

Surface Performance Grade	SPG 67				SPG 73				SPG 79			
	-13	-19	-25	-31	-13	-19	-25	-31	-13	-19	-25	-31
Average 7-day Max pavement surface design temperature, °C	<67				<73				<79			
Min pavement surface design temperature, °C	>-13	>-19	>-25	>-31	>-13	>-19	>-25	>-31	>-13	>-19	>-25	>-31
Original Hot-Applied Binder												
Flash point temp, T 48, Min, °C	230											
Viscosity, T 316: Max 0.15 Pa*s, test temp., °C	205											
Original Performance Properties												
Dynamic Shear, T 315: G*/sin δ, Min 0.65 kPa, Test temp @ 10 rad/s, °C	67				73				79			
Phase angle (δ), Max, @ temp. where G*/sin δ = 0.65 kPa	–	80	80	80	80	80	80	80	80	80	80	80
Pressure Aging Vessel Residue (R 28)												
PAV aging temperature, °C	100				100				100			
Creep stiffness, T 313: S, Max 500 MPa, Test temp. @ 8 sec., °C	-13	-19	-25	-31	-13	-19	-25	-31	-13	-19	-25	-31

Fig. 2. SPG Specification for Hot-Applied Asphalt Binders and Emulsion Residues (TxDOT SP 300-011).

3. *Emulsion Performance-Graded (EPG) Specification*

NCSU conducted research in NCHRP Project 09-50 (Performance-Related Specifications for Asphaltic Binders Used in Preservation Surface Treatments) to establish emulsion performance-graded (EPG) specification frameworks for chip seals and slurry seals/microsurfacings [8-12]. The EPG specification framework for chip seals addresses bleeding at high temperature and aggregate loss at low temperature using emulsion residue testing. In addition, the EPG specification framework addresses constructability concerns related to storage stability, sprayability, and drain-out through fresh emulsion (non residue) testing. The tests in the EPG framework rely on the DSR and RV equipment used in AASHTO M 320 and M 332. Key elements of the EPG specification include:

- Use of high and low surface pavement temperatures in 6°C increments shifted by 3°C at both high and low temperatures to reflect representative conditions;
- Use of traffic-dependent grading limits similar to AASHTO M 332;
- Characterization of fresh emulsion properties during construction including:
    - sprayability and drain-out using a three-step shear test conducted in the RV;
    - storage stability using a modified version of ASTM D6930 with viscosity measurements in the RV; and

    - particle charge and size, demulsibility, solubility, and float using existing procedures.

- Recovery of emulsion residue following AASHTO R 78 Procedure B;
- Requirement of a maximum limit for the non-recoverable creep compliance (J_{nr}) (AASHTO T 350) of unaged residue at the high-temperature grade to address bleeding; and
- Requirement of a maximum limit for the dynamic shear modulus (G^*) at a critical phase value (δ_c) of unaged residue, measured via DSR frequency sweep tests at 5°C and 15°C (termed the 5-15 procedure) to address aggregate loss in chip seals at low temperatures.

The EPG specification was established by correlating laboratory chip seal performance with residual binder properties using a wide range of commercial emulsions that had demonstrated satisfactory performance from locations throughout the U.S. and so-called 'poor-performing' emulsions that had been manufactured by suppliers intentionally to perform poorly when mixed with aggregate despite meeting current emulsion specifications. Limited short-term field validation of the developed specifications was conducted as part of the NCHRP 09-50 project. Efforts to identify the residual binder properties that correlate with aggregate loss at intermediate temperatures were unsuccessful. It was determined that aggregate loss at intermediate temperatures was driven by the incompatibility between the emulsion and aggregate and could not be captured by binder testing alone.

NCHRP Report 837 [8] and four peer-reviewed journal publications [9-12] document the EPG specification development. The EPG specification shown in Fig. 3 is available as an Attachment to NCHRP Report 837.

	Chip Seal Emulsion Performance Grade											
	EPG 61				EPG 67				EPG 73			
	-13	-19	-25	-31	-13	-19	-25	-31	-13	-19	-25	-31
Average 7-day Maximum Pavement Surface Design Temperature, °C[a]	<61				<67				<73			
Minimum Pavement Surface Design Temperature, °C[a]	>-13	>-19	>-25	>-31	>-13	>-19	>-25	>-31	>-13	>-19	>-25	>-31
Proposed Test Methods[b]	**Proposed Testing Temperature (°C)**											
Tests on Original Emulsion												
Storage Stability Modified AASHTO T 59 Measured responses: Rotational viscosity, η, A – 24-hour separation ratio (Rs): 0.5 to 1.5 B – 24-hour stability ratio (Rd): max. 2	60											
Sprayability Modified AASHTO TP 48 Measured response: Viscosity @ 3 shear rates, Max. 400 cP @ high shear rate (150 rpm)	60											
Resistance to Drain – Out Modified AASHTO TP 48 Measured response: Viscosity @ 3 shear rates, Min. 50 cP @ low shear rate (5 rpm)	60											
Demulsibility AASHTO T 59 Measured response: % demulsibility Min. 40% (anionic) Min. 60% (cationic)	25											
Particle Charge AASHTO T 59 Measured response: particle charge Positive (cationic)	25											
Sieve Test AASHTO T 59 Measured response: % mass Max. 0.1%	25											
Solubility AASHTO T 44 Measured response: % solubility Min. 97.5%	25											
Float[c] AASHTO T 50 Measured response: float time Min. 1200 seconds	60											
Percent Residue AASHTO R 78 Measured response: % residue Min. 65% (cationic) Min. 63% (anionic)	25											
Tests on Residue Recovered Using AASHTO R 78-Method B												
Resistance to Bleeding and Rutting AASHTO T 350 Measured response: Non recoverable creep compliance, J_{nr} Max Jnr @ 3.2 kPa, 8 kPa^{-1} (low traffic) Max Jnr @ 3.2 kPa, 5.5 kPa^{-1} (medium traffic) Max Jnr @ 3.2 kPa, 3.5 kPa^{-1} (high traffic)[d]	61				67				73			
Resistance to Low Temperature Raveling DSR Temperature Frequency Sweep Measured response: $\lvert G^*\rvert$ at critical phase angle, δc Max. $\lvert G^*\rvert$ @ δc: 30 MPa (low traffic) Max. $\lvert G^*\rvert$ @ δc: 20 MPa (medium traffic) Max. $\lvert G^*\rvert$ @ δc: 12 MPa (high traffic)	5°C and 15°C											
	Critical phase angle, δc (°)											
	51	48	45	42	51	48	45	42	51	48	45	42

a Pavement surface temperatures are estimated from air temperatures using an algorithm contained in the LTPP Bind program, or may be provided by the specifying agency.

b Vialit testing should be performed in accordance with British Standard EN12272-3 to measure resistance to aggregate loss due to compatibility issues between aggregate and emulsion at the intermediate temperature grade, which is the average of the high and low emulsion performance grades, plus 4 degrees.

c For high float emulsions only.

Fig. 3. EPG Specification for Emulsion Residues Used in Chip Seals [8].

4. AASHTO TSP·2 ETF DRAFT SPECIFICATION

The AASHTO TSP·2 ETF recognized that there were two similar, but different specification systems proposed for asphalt emulsions used in chip seals. Table 1 provides a comparison of the previous research efforts.

Table 1: Comparison of SPG and EPG Specifications.

Item	SPG	EPG
Developing Institution	Texas A&M Transportation Institute	North Carolina State University
Applications	Chip seal emulsions and hot-applied binder	Chip seal and microsurfacing emulsions
Grade Definition	Grades based on high and low surface pavement temperatures, e.g., SPG/EPG 67-19	
Residue Recovery	AASHTO R 78 Procedure B	
High-temperature Specifications	Minimum limit for *G*/sinδ* (AASHTO T 315) of unaged residue at the high temperature grade to address bleeding	Maximum limit for J_{nr} (AASHTO T 350) of unaged residue at the high-temperature grade to address bleeding in chip seals and rutting in microsurfacings
Low-temperature Specifications	Maximim limit for *S*(*8*) (i.e., creep stiffness at 8 seconds) (AASHTO T 313) of PAV-aged (AASHTO R 28) residue at the low-temperature grade to address aggregate loss	Maximum limit for *G** at critical phase value (*δc*) of unaged residue, measured via frequency tests of unaged residual binder at 5°C and 15°C (‘5-15’ procedure) to address aggregate loss in chip seals and thermal cracking in microsurfacings
Polymer Identification	Maximum limit for *δ* at the continuous high-temperature grade	Not included in the specification
Traffic Considerations	Grade bumping for high traffic levels similar to AASHTO M 320	Traffic-dependent grading limits similar to AASHTO M 332

Note that efforts to identify the residual binder properties that correlate with aggregate loss at intermediate temperatures in the development of both the EPG and SPG specifications were unsuccessful. The EPG and SPG research teams found that aggregate loss at intermediate temperatures was driven by the incompatibility between the emulsion and aggregate and could not be captured by binder testing alone [5, 11]. Thus, aggregate loss at intermediate temperatures is not considered in the EPG and SPG specifications and is recommended to be evaluated during the design process.

Seeking to better understand how the two specification systems worked and to reach a consensus on a path forward, the AASHTO TSP·2 ETF conducted an initial round-robin testing program in 2017 that included participation by three supplier laboratories who were provided 17 samples representing modified and unmodified asphalt emulsions used across the U.S.. The purpose of the round-robin testing program was to evaluate how asphalt emulsion residue for chip seals would be graded in the SPG and EPG specification systems and understand some of the testing and analysis challenges. The grades that were determined using each specification were compared to the climate conditions that corresponded to the location where the emulsion had been used successfully in field projects. The repeatability and reproducibility of the test results were also assessed. The round-robin program results demonstrated the following [13, 14]:

- The $G^*/sin\delta$ results generally led to the expected SPG high-temperature grade. However, the reproducibility of the test results exceeded expectations for testing conducted in accordance with AASHTO T 315. The increased error in testing reproducibility was speculated to be related to residual binder storage time, suggesting that storage conditions and time constraints could be included in future specifications.
- Phase angle values at the continuous high-temperature grade defined by the SPG specifications did not consistently differentiate between modified and unmodified binders. Identifying the presence of polymer modification may require measurements that are not performance-related, similar to Superpave PG Plus tests.
- Multiple stress creep and recovery (MSCR) tests that were conducted using emulsion residue often yielded EPG high-temperature grades that matched the target grade. However, the non-recoverable creep compliance (J_{nr}) values of the emulsion residue at these EPG high-temperature grades were very high. Two reasons for the high J_{nr} values compared to typical Superpave PG results are: (1) the test temperatures were 3°C higher than corresponding PG temperatures and (2) the emulsion residues had not undergone RTFO aging (AASHTO T 240). Also, DSR measurements of such high J_{nr} values could be compromised by inertial effects. The ETF recognized the merits of the MSCR test, given its implementation in asphalt binder purchase specifications. However, the ETF suggested that the test method should be refined to include a reduced test temperature and/or reduced stress levels.
- The low-temperature grades determined using the $S(8)$ parameter (Table 1) were very similar for all 17 emulsions evaluated. Therefore, $S(8)$ may not be able to discriminate between the performance of different residues.
- The BBR test results demonstrated that the $S(8)$ parameter (Table 1) is highly correlated with the standard BBR creep stiffness measured at 60 seconds of loading, $S(60)$. The $S(8)$ results are generally more variable than the $S(60)$ results, suggesting that $S(60)$ merits consideration if BBR testing is included in future specifications.
- The low-temperature grades determined using the EPG 5-15 procedure yielded results that generally matched expectations, based on the target grades used in the emulsion formulation. However, the results demonstrated poor repeatability and reproducibility in some cases. The ETF suggested that the elimination of high loading frequencies and simplification of the analysis procedure may reduce test variability. Consideration of aging using the 5-15 procedure is not straightforward and would require investigation should aging be incorporated in future emulsion specifications.

A subsequent round-robin study was conducted within the ETF in 2018 to validate some of the findings described previously and address additional questions. That study included 11 asphalt emulsions and five laboratories, the three laboratories that participated in the initial 2017 round robin along with two other supplier laboratories. Some of the key takeaways from the analysis of the data collected were [15]:

- Consistency in the emulsion residue recovery procedure is important to minimize variability. Analysis showed that the preferred residue recovery procedure (AASHTO R78 Procedure

B) has higher than expected variability, particularly for high temperature results. The use of the procedure in AASHTO T59 Section 7 mitigates some of the variability, but changes the values.

- Phase angle limits for polymer identification generally separate modified from unmodified emulsion residues when the residue was obtained using the AASHTO R78 Procedure B recovery procedure.
    - The analysis indicated that a maximum phase angle of 84 degrees at the temperature where G*/sin δ was equal to 0.65 kPa appeared to generally segregate unmodified from modified residue.
    - The analysis further showed that a maximum phase angle of 80 degrees at the temperature where G*/sin δ was equal to 0.65 kPa appeared to generally segregate polymer modified (P) from latex modified (L) residues.
    - When the residue was obtained using the AASHTO T59 Section 7 recovery procedure, the higher recovery temperature (135°C) had a significant effect on the latex modified emulsions, resulting in those residues also having a phase angle that was lower than the criterion of 80 degrees maximum for these materials.
- Intermediate temperature properties in the EPG system appear to be strongly impacted by the expected low temperature grade with higher values of G* at δc as the low temperature grade decreased, regardless of whether the residue was unmodified or modified.
- The MSCR limits in the proposed EPG Specification may need to be re-evaluated as analysis indicated that a G*/sin δ value of 0.65 kPa is comparable to a $J_{nr,3.2}$ value of approximately 17.6 kPa^{-1}. This is approximately twice as high as the maximum criterion for low traffic in the EPG Specification.
- The variability of the $J_{nr,3.2}$ parameter obtained from MSCR testing following AASHTO T 350 is as high or higher than was seen for the variability of the same parameter using paving grade hot mix asphalt binders. The expectation is that the variability observed in the residue recovery procedure contributes to the higher variability.
- Performing MSCR testing at a colder test temperature by 6°C compared to the EPG high temperature grade appears more appropriate for discrimination of results for modified and unmodified emulsion residues at 0.1 kPa shear stress ($R_{0.1}$). For the 11 samples in this round-robin testing program, the average $R_{0.1}$ value for unmodified emulsion residue was 4%. By contrast, the average $R_{0.1}$ value was 42% for latex-modified emulsion residue and 57% for polymer-modified emulsion residue.

Based on these results, the ETF developed the working standard shown in Fig. 4 that formed the starting point for ongoing NCHRP Project 09-63 (A Calibrated and Validated National Performance-Related Specification for Emulsified Asphalt Binder) discussed in the next section.

Emulsion Performance Grade	EPG 55					EPG 61					EPG 67			
	-19	-25	-31	-37	-43	-13	-19	-25	-31	-37	-13	-19	-25	-31
Surface design high temperature[1], °C	< 55					< 61					< 67			
Surface design low temperature[1], °C	> -19	> -25	> -31	> -37	> -43	> -13	> -19	> -25	> -31	> -37	> -13	> -19	> -25	> -31
Tests on Recovered Residue (AASHTO R78, Procedure B)														
High Temperature Parameter														
$G^*/\sin\delta \geq 0.65$ kPa, 10 rad/s @ Test Temperature, °C[2]	55					61					67			
Low Temperature Parameter														
G^* at δ_c, MPa[3] Low Traffic[4] $G^* \leq 30$ MPa @ δ_c, degrees High Traffic[5] $G^* \leq 15$ MPa @ δ_c, degrees	48	45	42	39	36	51	48	45	42	39	51	48	45	42
OPTIONAL Polymer Presence Indicator														
Max. δ at $T_{c,high}$, degrees[6]	n/a	n/a	n/a	84	80	n/a	n/a	n/a	84	80	n/a	n/a	84	80

NOTES:

1 Determined at the pavement surface to represent the high and low design temperature for the EPG. Temperatures may be determined from experience or may be estimated using equations LTPPBind Online, modified to represent the expected surface temperature. High surface temperatures are generally 3°C to 4°C greater than those determined for PG asphalt binders used for paving.

2 AASHTO T315 is used to determine the $G^*/\sin\delta$ value of the EPG asphalt binder.

3 G^* at δ_c is determined using temperature-frequency sweep testing at 5 and 15°C following the research test procedure described in NCHRP Report 837.

4 Low traffic is defined as having an AADT of 1,000 vehicles or less.

5 High traffic is defined as having an AADT greater than 1,000 but less than 20,000 vehicles.

6 Phase angle (δ) is determined at the continuous high temperature grade – $T_{c,high}$ – where $G^*/\sin\delta = 0.65$ kPa. Two temperatures are needed – one where $G^*/\sin\delta < 0.65$ kPa and one where $G^*/\sin\delta > 0.65$ kPa – so that the phase angle can be interpolated at the temperature where $G^*/\sin\delta = 0.65$ kPa.

Fig. 4. ETF Blended Specification for Emulsion Residues Used in Chip Seals.

This blended specification includes common elements from the EPG and SPG specifications (e.g., surface temperature is utilized and AASHTO R 78 Procedure B is used for emulsion residue recovery) and adopts the SPG specifications to determine the high-temperature grade and the EPG specifications to determine the low-temperature grade. Other relevant details of this standard include:

- Use of two traffic levels for low-temperature grading,
- Removal of consideration of aging, and
- Provision of an optional polymer identification procedure like the one in the SPG specification.

5. *Emulsified Asphalt Performance Graded (EAPG) System*

The Asphalt Institute began conducting research in NCHRP Project 09-63 in 2019 to further develop and validate the ETF Blended Specification. As part of the research program, field sections were identified at various locations in the U.S.. Samples were taken during construction at the project site, with an emphasis on testing the emulsion residue obtained following the residue recovery procedure in AASHTO R 78 Procedure B. With the properties of the emulsion residue determined at the time of construction, follow-up site visits were conducted annually. As part of these follow-up visits a performance evaluation of the chip seal surface treatment was conducted and samples were taken at the site and returned to the laboratory to be subjected to extraction/recovery procedures. Once the extracted and recovered binder was recovered from the chip seal, it was tested using the same procedures as conducted on the emulsion sampled at the time of construction. The expectation was that the recovered binder properties would: (1) provide an indication of the level of aging that occurred in service, and (2) would relate to any observed distress.

NCHRP Project 09-63 project is ongoing but has made a few discoveries and suggested revisions that could impact a future performance-graded specification for emulsion residue. These include the following [16, 17]:

- Since the draft ETF specification is a blend of the SPG and EPG specifications, it seemed inappropriate to use the same acronym (EPG) as one of the specifications. This could cause unnecessary confusion. Thus, the research team decided on referring to the blended specification as the EAPG (Emulsified Asphalt Performance-Graded) Specification.
- Proper execution of the emulsion residue recovery procedure is critical to obtaining quality test results and understanding how the parameters and proposed specification criteria may relate to the performance of the chip seal. The high level of variability observed within and between laboratories in this research project as well as the ETF round-robin studies suggests that the residue recovery procedure (AASHTO R 78 Procedure B) may need additional review and revision. An alternate residue recovery procedure such as AASHTO R 78 Procedure A may also need to be offered as an option for laboratories.
- Despite positive findings relating G* at a critical phase angle (δ_c) to distress at intermediate/low temperature, the proposed ETF parameter unfortunately does not behave rationally with aging. At a given value of δ_c, PAV aging causes G* to decrease, which is a counterintuitive response, resulting in an improvement in the ability of the emulsion residue to meet a given maximum specification value as it ages. Other parameters being considered to evaluate durability and cracking performance of paving grade hot mix asphalt binders, such as phase angle at a given stiffness or the Glover-Rowe parameter, may be options in the EAPG Specification.
- At the outset of the research project, the preference of the research team was not to use any long-term aging procedures, like the PAV, due to operational challenges, such as the amount of residue that would be needed to perform PAV conditioning. Evaluation of the aging occurring in the field sections after just one year may justify the need to include some level of aging in the draft specification.

6. Conclusion

Specifications for chip seal binders in service (emulsion residue or hot-applied asphalt binder) have been studied in the U.S. for the past twenty years. The goal of these studies has been to progress from empirical specifications in which the residue is obtained after high temperature distillation, which is not representative of the temperature the asphalt emulsion experiences in construction or in service, and tested using empirical tests across a limited temperature spectrum to judge its acceptability and expected performance with respect to critical distresses. Low temperature residue recovery procedures are available and in use, with the expectation that they will completely replace the standard high temperature distillation in the near future. Recovered emulsion residue can be tested using the same equipment, and with similar tests, as is used in the PG specification for paving grade hot mix asphalt binders. A draft specification for emulsion residue, based on the results of research conducted by TTI and NCSU, is currently being evaluated through NCHRP research to assess how the parameters and specification criterion relate to the distresses experienced by chip seals. The result of all this effort is an expectation that a validated national performance-related specification for emulsified asphalt binders used in chip seals will be implemented and in wide use in the U.S. in the next 5-10 years.

7. ACKNOWLEDGEMENTS

The authors thank the National Cooperative Highway Research Program and the Texas Department of Transportation for providing research funding associated with the evolution of these specifications. Thanks are also due to the AASHTO TSP2 ETF members and leaders Colin Franco and Chris Lubbers for their guidance, input, and efforts to continue this evolution. The authors also acknowledge the laboratory and field staff from the various research partners for their work, the materials suppliers for donations, the contractors associated with field sections for their collaboration, and the partnership of agencies and industry to move forward.

8. DISCLAIMER

NCHRP Project 09-63 is sponsored by the Transportation Research Board under the NCHRP Program. Findings reported are considered a work in progress. Contents of this research may have not been reviewed by the project panel of NCHRP, nor do they constitute a standard, specification, or regulation.

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