TechBrief

WRSC-TB-20-01

May 2020

Author(s):

Gaylon Baumgardner

Pavement Engineering & Science Program

University of Nevada, Reno

PES Program
1664, N. Virginia Street, MS 258,
Reno, NV 89557.

Multiple Stress Creep and Recovery (MSCR) Implementation and Transition

This Technical Brief provides a review and update on the Multiple-Stress Creep and Recovery (MSCR) specification parameters and support for implementation of AASHTO M 332: Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep and Recovery (MSCR) Test.

Introduction

The primary objective of this document is to assist deployment and transition from AASHTO M 320-2017, *Standard Specification for Performance-Graded Asphalt Binder* to AASHTO M 332-2019, *Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep and Recovery (MSCR)* Test. Additionally it is expected to provide technical information on the background of the MSCR test and the AASHTO M 332 specification with implementation activities.

Background

The early 1990s saw the advent of the Superpave performance-graded (PG) binder specification, AASHTO M 320, *Standard Specification for Performance-Graded Asphalt Binder*. The AASHTO M 320 specification considers climatic conditions, including high and low pavement temperatures, as well as traffic loading conditions, to include speed and volume accounted for through "temperature grade bumping." Additionally, AASHTO M 320 incorporates short- and long-term conditioning to simulate aging of the binder within the testing framework to consider the binders performance over time with respect to permanent deformation and cracking. This implies that test measurements be made at temperatures and loading rates consistent with conditions existing in the pavement.

While the AASHTO M 320 specification was proposed to be equally applicable to both neat and modified binders, many State Departments of Transportation (State DOTs) question its applicability to modified binders. For example, an I-80 test section in Nevada clearly shows the difference between modified and unmodified asphalt binders and their performance grading. On this test section two different binders were evaluated in the same mixes; one binder was an unmodified PG 67-22 and the other was a polymer modified PG 63-22. Conceptually, the PG 67-22 would be much more rut resistant than the PG 63-22 because it reaches its limiting stiffness at a much higher temperature. However, this was not the case. In the field the straight run PG 67-22 exhibited 15mm rutting in the same mix that showed absolutely no rutting with the polymer modified PG 63-22.

As such, supplemental tests and specifications were implemented (referred to as Superpave PG Plus or SHRP Plus) to ensure Nevada would get polymer modified asphalt binders (D'Angelo 2002).

While PG Plus tests may indicated the presence of polymer they present a problem because in most cases they do not relate to performance. A performance related binder specification to characterize both modified and unmodified asphalt binders based on their performance characteristics would be of value. The specification should be based on asphalt binder performance related properties that have been validated using mixture performance tests. Since it is intended as a purchase specification, it should also involve tests that are easy and quick to run. To address industry concerns, the multiple stress creep and recovery (MSCR) test parameter was developed as a PG binder specification test that is both performance related and applicable to all binders whether neat or modified.

As with AASHTO M 320 specification testing, the MSCR test is performed on the dynamic shear rheometer (DSR) using the same fixtures and techniques as the standard DSR test procedure; AASHTO T 315-2017*, Standard Method of Test for Determining the Rheological Properties of Asphalt Binders Using a Dynamic Shear Rheometer (DSR)*. Using the DSR, MSCR testing employs a well-established creep and recovery concept to evaluate the binder's potential for permanent deformation (D'Angelo et Al. 2007). Creep and recovery cycles are generated by applying a 1-second creep load to the asphalt binder sample followed by a 9-second recovery period, completing the cycle shown in Figure 1.

The test is initiated with the application of a low stress (0.1 kPa) for 10 creep/recovery cycles followed by increasing the stress to 3.2 kPa and repeating the sequence for an additional 10 cycles. The MSCR test procedure, AASHTO T 350-2018, *Standard Method of Test for Multiple Stress Creep and Recovery (MSCR) Test of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)*, captures the non-recoverable creep compliance (Jnr) and percentage of recovery (Percent Recovery) during each loading cycle. Dividing the

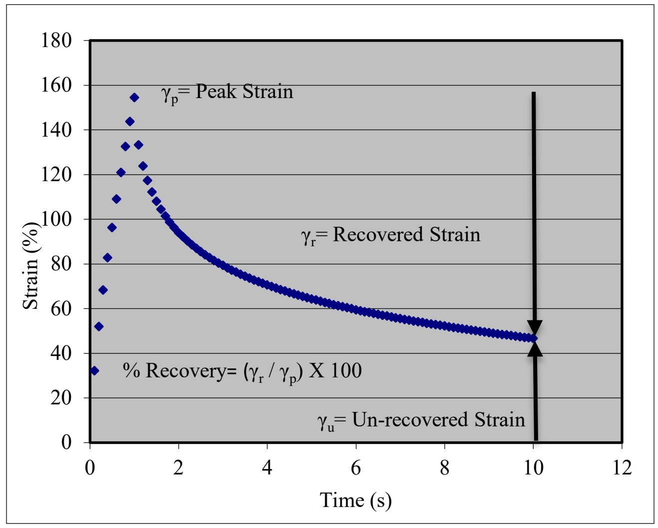

Figure 1. MSCR Creep and Recovery Cycle.

un-recovered strain by the applied stress during the creep portion of the loading normalizes the response and provides the J_{nr} value. Figure 2 shows a plot of ten normalized creep and recovery cycles from MSCR testing of a polymer modified binder and the formula for determination of the non-recoverable compliance.

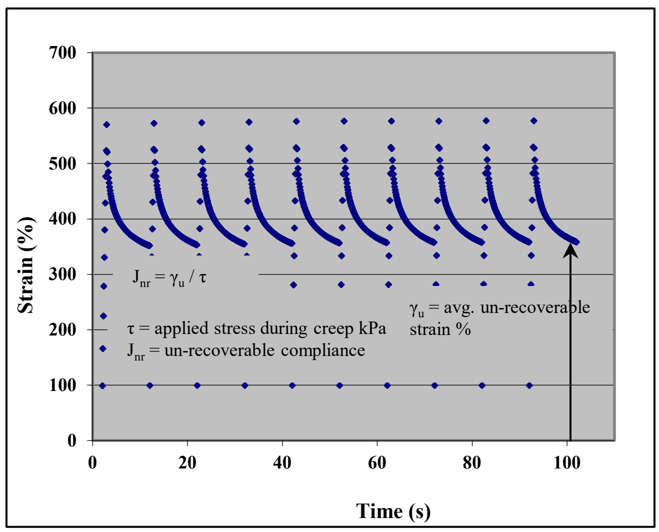

Figure 2. Examples of Modified Asphalt Binder Response to Repeated Loading (D'Angelo et Al. 2007).

Material response in the MSCR test is significantly different than the response under the loading invoked in the AASHTO M 320 PG system DSR testing. In the AASHTO M 320 PG system the high temperature parameter, G*/sinδ, is measured by applying an oscillating load to the binder at very low strain. This is one of the reasons why the

AASHTO M 320 PG high temperature parameter does not accurately represent the ability of polymer modified binders to resist rutting.

Under the very low levels of stress and strain present in the dynamic shear modulus testing the polymer network is never effectively engaged. Basically, in the existing AASHTO M 320 PG specification, the polymer is only measured as a filler that stiffens the asphalt. In the case of the MSCR test, higher levels of stress and strain are applied to the binder, better representing what occurs in an actual pavement. By using the higher levels of stress and strain in the MSCR test, the response of the asphalt binder captures not only the stiffening effects of the polymer, but also the delayed elastic effects.

Overview of Superpave PG Grading Specifications

AASHTO M 320

The AASHTO M 320 PG binder grades are specified for climatic conditions ranging from high temperature grades of PG 46 to PG 82 and low temperature grades of -10 to -40. This is established based on the accumulated degree days above 10°C to determine the high pavement design temperature, and minimum pavement design temperature.

The specification limiting parameters are based on rheological properties of the asphalt binder measured over a range of temperatures and aging conditions. Various pieces of equipment are used to measure stress strain relationships in the binder, at the specified test temperatures where very low stress and strains are employed in testing of asphalt binders. This equipment includes the DSR and bending beam rheometer (BBR). Measuring binder rheological properties over a wide range of temperatures, loading conditions, and aging conditions allows performance relationships to be established between the measured properties and pavement structure.

Traffic speed and loading parameters are addressed through a process referred to as "grade bumping" in accordance with AASHTO M 323-2017, *Standard Specification for Superpave Volumetric Mix Design* (AASHTO M 323-2017). Adjustments to the high-temperature binder grade are made based on traffic speed and traffic level according to Table 1. The testing temperature for the PG high temperature grade is increased above the climate temperature in increments of six degrees by one to two bumps depending on design traffic loads and loading rate. Requiring the same DSR specification criteria at higher testing temperature essentially ensures a more robust binder to address increased traffic loadings; however, as stated, this approach has been shown not to identify the true performance characteristics of modified asphalt binders.

Table 1. AASHTO M 323 High Temperature PG Binder Grade Adjustments.

Design ESALs (Million)	Adjustment to the High-Temperature Grade of the Binder		
	Traffic Load Rate		
	Standard	Slow	Standing
< 0.3	–	–	–
0.3 to < 3	–	1	2
3 to < 10	–	1	2
10 to < 30	–	1	2
≥ 30	1	1	2

AASHTO M 332

The AASHTO M 332 specification covers asphalt binders graded by performance related criteria using the MSCR test. Grading designations are established based on the accumulated degree days above 10°C to determine the high pavement design temperature, minimum pavement design temperature, and relative traffic loadings. As with AASHTO M 320, typical PG binder grades are specified for climatic conditions ranging from high temperature grades of PG 46 to PG 82 and low temperature grades of -10 to -40.

Also, as with the AASHTO M 320 PG binder specifications, AASHTO M 332 PG binder specification limiting parameters are based on rheological properties of the asphalt binder measured over a range of temperatures and aging conditions. Identical equipment, DSR and BBR, are used to measure stress strain relationships in the binder at the specified test temperatures. Addition of the AASHTO T 350 MSCR test protocol and applying higher levels of stress and strain to the binder better represents what occurs in an actual pavement. Measuring binder rheological properties over a wide range of temperatures, loading conditions, and aging conditions allows performance relationships to be established between the measured properties and pavement structure.

Grade bumping in the AASHTO M 332 high temperature specification is implemented differently with the J_{nr} based specification. With AASHTO M 332 the value of J_{nr} determines whether a PG binder is suitable for standard, heavy, very heavy, or extreme traffic loadings, Table 2.

Table 2. AASHTO M 332 High Temperature PG Grade Designations for a PG 64-XX Grade.

New PG Grade Designation	MSCR J_{nr} Parameter Value	Design Traffic Level
PG 64S-XX	Less than or Equal to 4.5	Standard < 3 million ESALs
PG 64H-XX	Less than or Equal to 2.0	Heavy > 3 million ESALs
PG 64V-XX	Less than or Equal to 1.0	Very Heavy > 10 million EASLs
PG 64E-XX	Less than or Equal to 0.5	Extreme > 30 million ESALs

Summary Comparison of AASHTO M 320 and AASHTO M 332

Performance graded specifications AASHTO M 320 and AASHTO M 332 differ primarily with respect to high temperature rheological parameters and related testing protocols. Safety and constructability parameters of both AASHTO M 320 and AASHTO M 332 are identical. Flash point (AASHTO T 48) specifications for both is a minimum of 230°C and viscosity (AASHTO T 316) at 135°C is limited to a maximum of 3 Pa·s to evaluate pumpability. Both specifications also restrict mass change after rolling thin-film oven (RTFO) aging to a maximum of one percent (1 percent) for either a positive (mass gain) or a negative (mass loss) change in mass.

Original DSR

Table 3 presents a general overview comparing the rheological parameters between AASHTO M 320 and AASHTO M 332. From Table 3, it is apparent that original binder DSR (ODSR) testing for both AASHTO M 320 and AASHTO M 332 is performed in accordance with AASHTO T 315-2017, *Standard Method of Test for Determining the Rheological Properties of Asphalt Binders Using a Dynamic Shear Rheometer (DSR*). AASHTO T 315 ODSR testing for both specifications uses standard 25mm parallel plate fixtures with testing at 10 radians/second.

The AASHTO M 320 specification calls for testing at the Long-Term Pavement Performance (LTPP) web-based binder selection tool "LTPPBind™" maximum pavement design temperature, with temperature grade bumping to account for traffic as presented in Table 1. ODSR testing in the AASHTO M 332 specification is at the LTPPBind™ regional climate temperature. There is **NO** temperature grade bumping, so **ALL** tests are performed at the LTPPBind™ regional climate temperature. ODSR limits, for the DSR specification parameter $G^*/\sin\delta$, remain at a minimum of 1.0 kPa for both specifications. Since all AASHTO M 332 testing is performed at the LTPPBind™ regional climate temperature, it is important to note and understand that ODSR results from AASHTO M 332 H, V, and E grades are expected to be considerably higher than results from AASHTO M 320 temperature grade bumped grades approximately two-, to four-, to eight -fold, respectively.

RTFO DSR

From Table 3, primary differences between the AASHTO M 320 and AASHTO M 332 specifications exist in testing of aged binders. As with ODSR testing, AASHTO M 320 specifies oscillatory DSR testing of the RTFO-aged binder be performed in accordance with AASHTO T 315. AASHTO M 320 RTFO DSR (RDSR) testing also uses 25mm parallel plate fixtures with testing at 10 radians/second at the LTPPBind™ maximum pavement design temperature, and temperature grade bumping to account for traffic as presented in Table 1. AASHTO M 320 RTFO DSR (RDSR)

G*/sinδ limits are specified at a minimum 2.2kPa.

In the AASHTO M 332 specification, oscillatory DSR testing of RDSR binders is replaced by AASHTO T 350 MSCR testing. According to Table 3, AASHTO T 350 MSCR testing is performed at the LTPPBind™ maximum pavement design temperature; the LTPPBind™ regional climate temperature at the appropriate design reliability. Traffic considerations are accounted for through the MSCR non-recovered creep compliance specification parameter $J_{nr\ 3.2}$, as presented in Table 2. PG grade designations are established by the maximum and minimum LTPPBind™ pavement design temperatures with a designation of S (Standard), H (Heavy), V (Very Heavy), and E (Extreme). For example, PG 64H-22 would be a binder for a maximum pavement temperature of 64°C and a minimum pavement temperature of -22°C with a $J_{nr\ 3.2}$ parameter specification limit for "Heavy" traffic (> 3 million ESALs). From Table 3, the MSCR $J_{nr\ 3.2}$ parameter limit for "Standard" traffic (< 3 million ESALs) is a maximum of 4.5kPa, for "Heavy" traffic (> 3million to 10 million ESALs) is a maximum of 2.0kPa, for "Very Heavy" traffic (> 10 million to 30 million ESALs) is a maximum of 1.0kPa, and for "Extreme" traffic (> 30 million ESALs) is a maximum of 0.5kPa. Temperature grade bumping for traffic is not a consideration as traffic is addressed by the MSCR $J_{nr\ 3.2}$ parameter specification limits for the desired grade.

Pressure aging vessel (PAV)

PAV protocols for both AASHTO M 320 and AASHTO M 332 remain the same with aging temperatures of either 90, 100, or 110°C, based on regional simulated climate conditions. Oscillatory DSR testing of PAV-aged residue (PDSR) is performed in accordance with AASHTO T 315. The AASHTO T 315 PDSR testing for both specifications uses standard 8mm parallel plate fixtures with testing at 10 radians/second. PDSR testing and specification temperatures for both specifications are set as half of the differential of LTPPBind™ maximum and minimum pavement design limits plus 4°C. For example, a PG 64-22 AASHTO M 320 grade or a PG 64X-22 AASHTO M 332 grade would both have PDSR testing performed at 25°C (64-22=42, 42/2=21, 21+4 =25). Stiffness limits for the PDSR specification parameter, G*sinδ, for all AASHTO M 320 PG binders is a maximum of 5000kPa. AASHTO M 332 limits for PDSR G*sinδ for "S" traffic binders is also a maximum of 5000kPa; M 332 "H," "V," and "E" traffic binders are specified at a maximum of 6000kPa.

Low temperature creep stiffness for both AASHTO M 320 and AASHTO M 332 is determined at the LTPPBind™ minimum pavement design temperature in accordance with AASHTO T 313-2019, *Standard Method of Test for Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)*; specification limits are the identical.

Improvements Offered by AASHTO M 332

The addition of the MSCR test is an improvement to the PG binder specification in several ways:

- J_{nr} is better correlated with rutting potential than G*/sinδ.
- MSCR test results for modified and unmodified asphalt binders can be determined with the same test procedure, eliminating the need for additional tests, e.g. PG plus tests, to characterize high temperature performance of modified asphalt binders.
- Criteria are available to eliminate rutting-susceptible overly stress sensitive binders which were not captured by AASHTO M320.
- The percent recovery from the MSCR test does a better job of characterizing polymer modified asphalt binders, as well as being faster and easier compared to other "PG Plus" tests like elastic recovery (ER).
- MSCR testing is conducted at the actual pavement temperature, regardless of traffic loading, no artificial temperature bumping.

Table 3. General Comparison of AASHTO M 320 and AASHTO M 332

Performance Grade Parameters	AASHTO M 320	AASHTO M 332
Grade	**PG XX - XX**	**PG XX (S, H, V or E) - XX**
Maximum Pavement Design Temp, °C	< LTPPbind Regional Climate Temp	< LTPPbind Regional Climate Temp
Minimum Pavement Design Temp, °C	> LTPPbind Regional Climate Temp	> LTPPbind Regional Climate Temp
Original Binder		
Dynamic shear, AASHTO T 315: **G*/sinδ, min 1.00 kPa** **test temp @ 10 rad/s, °C**	LTPPbind Regional Climate Temp with Temp Grade Bump in accordance with AASHTO M 323	LTPPbind Regional Climate Temp **(No Temperature Bumping)**
Rolling Thin-Film Oven Residue (T 240)		
Dynamic shear, AASHTO T 315: **G*/sinδ, min 2.20 kPa** **test temp @ 10 rad/s, °C**	LTPPbind Regional Climate Temp with Temp Grade Bump in accordance with AASHTO M 323	N/A
MSCR, AASHTO T 350: **Standard Traffic "S"** **$J_{nr\,3.2}$, max 4.5 kPa^{-1}** **$J_{nr\,diff}$, max 75 percent** **test temp, °C**	N/A	LTPPbind Regional Climate Temp **(No Temperature Bumping)**
MSCR, AASHTO T 350: **Heavy Traffic "H"** **$J_{nr\,3.2}$, max 2.0 kPa^{-1}** **$J_{nr\,diff}$, max 75 percent** **test temp, °C**	N/A	LTPPbind Regional Climate Temp **(No Temperature Bumping)**
MSCR, AASHTO T 350: **Very Heavy Traffic "V"** **$J_{nr\,3.2}$, max 1.0 kPa^{-1}** **$J_{nr\,diff}$, max 75 percent** **test temp, °C**	N/A	LTPPbind Regional Climate Temp **(No Temperature Bumping)**
MSCR, AASHTO T 350: **Extremely Heavy Traffic "E"** **$J_{nr\,3.2}$, max 0.5 kPa^{-1}** **$J_{nr\,diff}$, max 75 percent** **test temp, °C**	N/A	LTPPbind Regional Climate Temp **(No Temperature Bumping)**
Pressurized Aging Vessel Residue (R 28)		
PAV Aging Temp, °C	Based on Regional Simulated Climate Conditions, either 90, 100 or 110 °C	Based on Regional Simulated Climate Conditions, either 90, 100 or 110 °C
Dynamic shear, AASHTO T 315: **G* sinδ, max 5000 kPa** **test temp @ 10 rad/s, °C**	Half the Differential of Maximum and Minimum Pavement Design Temp plus 4 °C	N/A
Dynamic shear, AASHTO T 315: **"S"** **G* sinδ, max 5000 kPa** **test temp @ 10 rad/s, °C**	N/A	Half the Differential of Maximum and Minimum Pavement Design Temp plus 4 °C
Dynamic shear, AASHTO T 315: **"H", "V", "E"** **G* sinδ, max 6000 kPa** **test temp @ 10 rad/s, °C**	N/A	Half the Differential of Maximum and Minimum Pavement Design Temp plus 4 °C
Creep stiffness, AASHTO T 313: **S, max 300Mpa** **m-value, min 0.300** **test temp @ 60 s, °C**	10 °C Below the LTPPbind Minimum Pavement Design Temp	10 °C Below the LTPPbind Minimum Pavement Design Temp

Non-recoverable Creep Compliance (J_{nr})

The MSCR test parameter, J_{nr}, provides a high temperature binder criteria blind to binder modification. The J_{nr} parameter has been evaluated and related to rutting in different rut testers and on actual pavement sections as described below.

D'Angelo (D'Angelo et Al. 2007) evaluated binders from a field trial of polymer modified asphalt binders placed by the Mississippi Department of Transportation (MSDOT) in the summer of 1996 (Crawley 1996). This trial represented eight (8) modified asphalt binders and an AC-30 control asphalt binder used in pavement test sections on I-55 in Mississippi between north bound exits 208 to 220. A correlation of field rutting results to the J_{nr} parameter through MSCR testing of binders obtained from this field study is presented in Table 4.

Table 4. Ranking of MSDOT Field Trial Binders Using the J_{nr} Parameter, (D'Angelo et al. 2007).

Modifier	Continuous grade	Modification	Jnr 800Pa 64C	6 yr rut mm
Control	70-24	Neat	0.142	11
Cryo Rubber	75-28	80 mesh *GTR/10 %	0.052	7
Multigrade	72-24	Chemical Process	0.079	5
Ultrapave	70-27	*SBR/3.0 %	0.055	4.5
Sealoflex	82-27	*SBS/4.25 %	0.008	3
Styrelf	77-29	*SB/6.0 %	0.013	2
GTR 80	75-29	80 mesh *GTR/10 %	0.039	1.5

* GTR – Ground Tire Rubber; * SBR – Styrene Butadiene Rubber; * SBS – Styrene-Butadiene-Styrene; and * SB – Styrene-Butadiene

The MSCR test and J_{nr} parameter did a good job of ranking the binders related to highway pavement field rutting from the MSDOT project. As with any field study there is variability caused by materials and construction.

Stress Sensitivity

AASHTO M 332 provides criteria from MSCR testing to eliminate rutting-susceptible, overly stress sensitive binders, which were not captured by AASHTO M 320. Therefore, an additional condition of the AASHTO M 332 specification is a comparison of the J_{nr} compliance results between the low stress 0.1kPa loading and the higher stress 3.2kPa loading. The specification limits the difference between the J_{nr}@3.2kPa and J_{nr}@0.1kPa to a maximum of 0.75 percent of the J_{nr}@0.1kPa. This parameter is expressed in AASHTO M 332 as J_{nrdiff}, max 75 percent. The reason for this specification limit is that some binders are very sensitive to stress level and exhibit yielding under high stresses. The intent is that the comparison be made when the J_{nr}@3.2kPa is close to the specification limit. If during use in the field the stress in the pavement should be higher than expected or the pavement may experience higher than expected temperatures, there would not be unexpected loss of strength of the binder. However, this is not an issue when the J_{nr} is well below the specification limit and or when the J_{nr} value is below 0.25.

A study done for the FHWA Binder Expert Task Group (ETG) on wax modified binders showed the significant stress sensitivity as seen in Figure 3 (Baumgardner et Al. 2009, Rowe et Al.2012). Waxes such as polyolefin and other similar waxes are known to yield under higher stresses. The wax modified binders have very small J_{nr} values at the 0.1kPa level but at 3.2 kPa lose significant stiffness. This wax study was one of the drivers to include the J_{nrdiff} in the binder specification to limit the types and amount of waxes that could be used to modify asphalt binder.

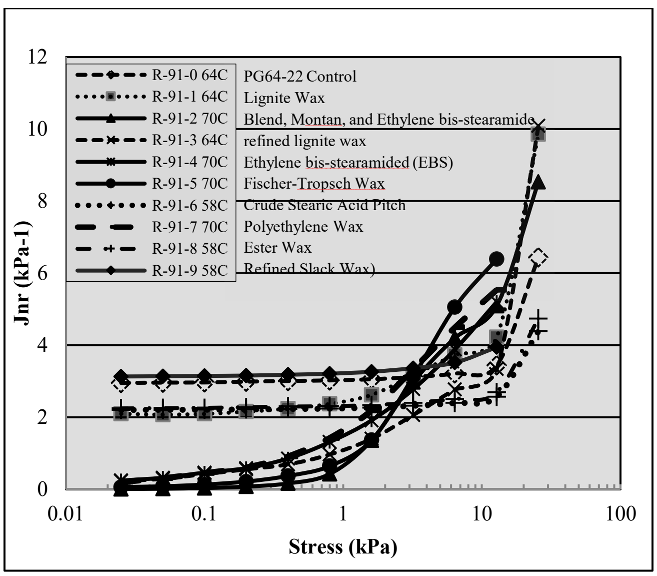

Figure 3. J_{nr} versus Stress of Wax Modified Asphalt Binders.

There has been high variability with J_{nr} results, one approach to reduce some of this variability is to increase the lower stress level. As presented in Figure 3, while 0.1kPa is well within the linear range for most binders, the linear response typically continues up to about a 0.8kPa stress level. Increasing the 0.1kPa stress to 0.8kPa increases the strain measured in the test helping reduce the issue with the measurement of very low strains.

To incorporate the 0.8kPa as the lower stress level is very simple. Currently there are 10 conditioning cycles at 0.1kPa, then 10 test cycles at 0.1kPa and 10 test cycles at 3.2kPa. The existing conditioning cycles at 0.1kPa would remain the same, but the lower stress test cycles would be increased to the 0.8kPa level followed by the 10 test cycles at 3.2kPa. The test would have the exact same total number of cycles and take the same amount of time to complete.

MSCR Percent Recovery

The MSCR percent recovery does a better job of characterizing polymer modified asphalt binders as well as being faster and easier compared to other "PG Plus" tests like ER. Rheological properties of modified asphalt binders depend on formulation variables. The most sensitive among them may be listed as modifier content, dispersion, curing, and the effect of additives, e.g. polyphosphoric acid (PPA). For example, dispersion of SBS in an asphalt binder depends on dispersion efficiency, blending time, and temperature as well as base asphalt binder compatibility and/or use of other additives. For asphalt binders tested according to AASHTO T 350, the percent recovery is intended to provide a means for determining the presence of elastic response and stress dependence of polymer modified and unmodified asphalt binders. Figure 4 (AASHTO M 332 2019, Appendix X1) presents the recommended specification limits from AASHTO T 350 for percent recovery as a function of J_{nr} 3.2 kPa of asphalt binders containing elastomeric polymers. Agencies may choose to use either this curve or the related equation for specification purposes.

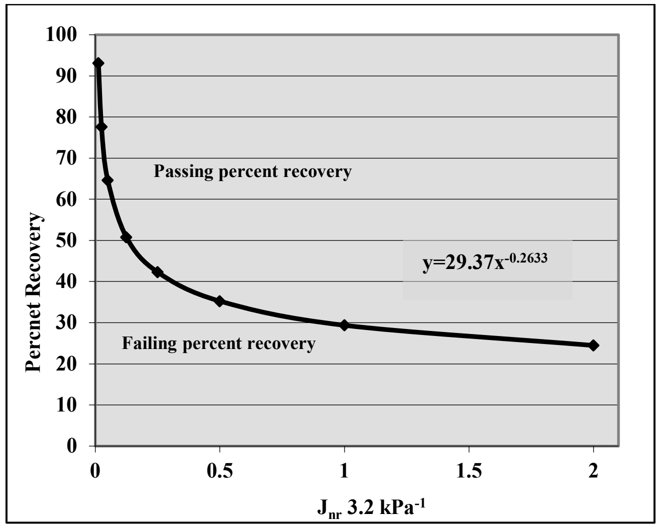

Figure 4. Non-recoverable Creep Compliance versus Percent Recovery.

The MSCR test also provides an alternative PG Plus test to identify the presence of polymer. Figure 5 presents the specification limit curve from AASHTO T 350 compared to results of several different modified binders tested at different temperatures (58, 64, 70, and 76°C). The relationship of modifier type, temperature and J_{nr} can easily be seen. All modified binders may not adhere to the proposed limit from AASHTO T 350. For example, binders modified with ground tire rubber (GTR) may not recover to the degree of virgin polymers. In such cases agencies have three options for specification of MSCR percent recovery: 1) construct MSCR percent recovery calibration curves and equations specific to the polymer modifier in question, 2) add a parameterization factor to the existing AASHTO T 350 specification limit curve to allow for reduced percent recovery, e.g. deduct 10percent for all J_{nr} 3.2 kPa specification limits, and/or 3) add a parameterization factor to the AASHTO T 350 percent recovery equation that equates to typical percent recovery results of the polymer modifier in question.

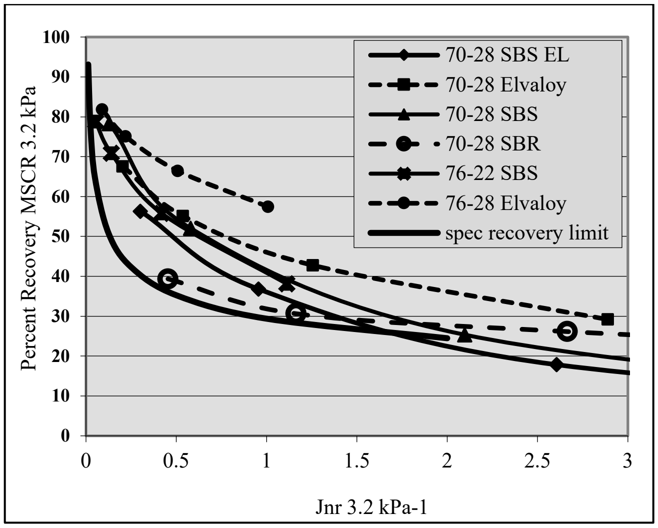

Figure 5. MSCR Percent Recovery for Various Binders Modified with Elastic Polymers.

MSCR Testing Temperature and Grade Bumping for AASHTO M 320 vs. AASHTO M 332

For the AASHTO M 320 specification DSR testing is done at the PG grade temperature unless grade bumping is used to account for traffic speed and traffic level per AASHTO M 323 (AASHTO M323-2017). It is important to understand that when grade bumping is used, the "LTPPBind™ regional climate temperature" does not change, only the DSR test temperature changes. Per AASHTO M 323, AASHTO M 320 specification testing is performed at higher (bumped) PG grade temperatures to account for traffic. While this is an accurate assumption for neat binders in the AASHTO M 320 specification, it is not the case for the AASHTO M 332 specification, nor is it the case with AASHTO R 92 *Standard Practice for Evaluating the Elastic Behavior of Asphalt Using the Multiple Stress Creep Recovery (MSCR) Test*, the standard practice used to evaluate the elastic response of an asphalt binder under shear creep and recovery (AASHTO R 92-2018).

With the AASHTO M 332 specification the grade of binder is changed to account for traffic based on J_{nr} criteria. The testing is not performed at "bumped" temperatures. If the LTPPBind™ regional climate grade is PG 64 then all high temperature testing is to be done at 64°C. If heavy traffic is expected, the J_{nr} specification limit is reduced, and the testing is still done at the "LTPPBind™ regional climate temperature. For example, the AASHTO M332 specification J_{nr} specification limit for standard fast-moving traffic is 4.5 or less and for slow moving or higher traffic volume the J_{nr} specification limit is a maximum of 2.0 or 1.0 to specify a more rut resistant material. Testing for each MSCR grade S, H, V or E, as listed in Table 2, would be done at the same LTPPBind™ regional climate temperature of 64°C. This allows for accurate evaluation of the binder at the expected pavement temperature for the regional climate.

Figure 6 presents results of MSCR testing of five AASHTO M 320 PG binders comparing MSCR J_{nr} 3.2 values at different test temperatures. It is apparent that different binders have different temperature sensitivity and illustrates the importance of testing at the LTPPBind™ regional climate temperature. The five binders, graded in accordance with AASHTO M 320, are: a non-modified PG 58-28 binder, a non-modified PG 70-22 binder, and three PG 70-28 binders. According to AASHTO M 323, all four of the modified grade binders would meet the high temperature limits of a two-grade bump to account for heavy standing traffic. However, while these binders might perform well in an LTPPBind™ 58°C regional climate, if used in an LTPPBind™ 70°C regional climate resistance to permanent deformation might be quite different with each.

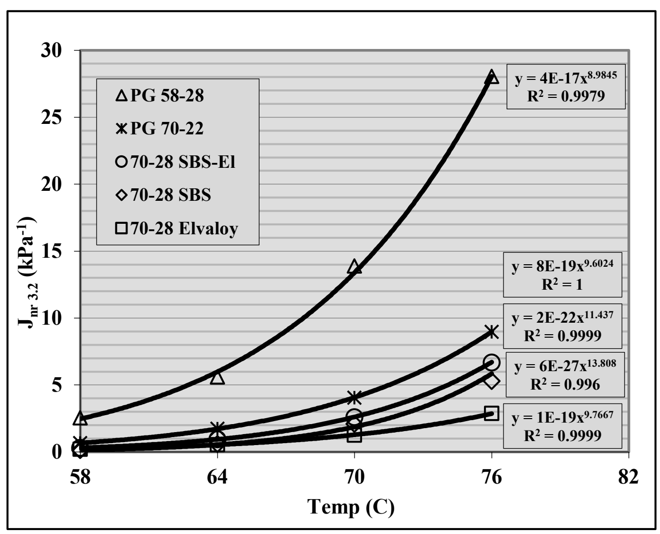

Figure 6. $J_{nr\ 3.2}$ Versus Temperature for Various AASHTO M 320 Graded PG 70 Binders.

Barriers to Implementation

Potential barriers to a State DOT implementing the AASHTO M 332 specification include the following:

- Status Quo – Satisfied with current practice, possible limits of staffing and return on investment.
- Agency fear of change and desire to get the same products used historically.
- Industry fear of grade proliferation.
- Specification name change and training.
- Loss of grade bumping option.

A description of each barrier and rationale for implementation follows.

Status Quo

While the agency may be happy with what is currently being supplied, the existing AASHTO M 320 specification has significant limitations. It was developed primarily for neat asphalt binders. Accommodations were made for modified systems, but these accommodations were limited to typical SBS type polymers used in the past. As new modifiers were introduced, the existing AASHTO M 320 may not identify the performance characteristics of these systems either positively or negatively. Many PG plus tests were added to adjust or overcome these problems. As newer modifiers are brought into the market this is likely continue to be a problem and there is no guarantee that the agency can expect continue to receive the same materials as in the past. This is a key reason for the need for a more performance related specification. Additionally, agencies have expressed concern that implementation could exceed existing staffing capabilities limiting the benefits and cost effectiveness of implementation.

Fear of Change

The famous question: "Are we going to get the same material we have received in the past with the new MSCR specification?" With any specification change there is no guarantee that material can be expected to stay the same. One key way to account for this is to thoroughly test the material using both specifications. This way any variations can be identified, and adjustments made to specification limits to accommodate changes. One example of this is where a highway agency switched from PG 76-22 to PG 64E-22. After implementation, it was observed that the new PG 64E grade was not quite as stiff as the PG 76 received in the past. Further evaluation identified that in the past the agency had been using a PG Plus specification with a very high elastic recovery. This had forced the suppliers to provide significantly higher AASHTO M 320 grade binder than would normally be supplied to meet a typical PG 76. When the agency switched to the MSCR PG 64E grade, the higher elastic recovery specification limit was not accounted for with a higher percent recovery when using the AASHTO M 332 specification. Once this was realized, the percent recovery limit was increased, and the AASHTO M 332 specification was easily adjusted to provide similar characteristics as the old specification.

Grade proliferation

Suppliers are concerned about grade proliferation. This was the same concern raised when the AASHTO M 320 specification was introduced. Just as in the past, agencies understand that they are better served to limit the grades of materials they use and not specify boutique grades for every project. Agencies may work with the suppliers as they have in the past to establish which grades are needed and typically used in any geographic location.

Specification changes

Any change in specifications may make changes to publications of specifications and training materials necessary. This is standard procedures for many highway agencies. Updates and added new specification are continually made to agency specifications. New special provisions are continually added, and training updated. Use of electronic documents has made it quite easy to do these updates. Almost all highway agency specifications are electronic now and expensive printing has been eliminated. There is always a transition period were personnel become familiar with new terminology and specification limits. A webinar, *"Using the MSCR Test in Asphalt Binder Specifications"* may be helpful in implementation and transition to AASHTO M 332. This webinar, available at no charge on the AI website, is based upon previous work supported by the AI and the U.S. Department of Transportation Federal Highway Administration (FHWA).

Grade bumping

As previously discussed, in the AASHTO M 332 specification the grade of binder is changed based on the J_{nr} compliance value as opposed to testing at different temperatures. If the LTPPBind™ regional climate grade is a PG 58 or PG 64, all high temperature testing is done at 58°C or 64°C. If heavy traffic is expected the specification limit is changed by requiring a lower J_{nr} value to reflect the increased stress the pavement is expected to experience, but testing is still done at the LTPPBind™ regional climate temperature; in the case of PG 58 or PG 64, either 58°C or 64°C. The AASHTO M 332 specification for standard fast-moving traffic J_{nr} limit is a maximum 4.5 and for slow moving or higher traffic volume the J_{nr} specification limit would be a maximum of 2.0 or 1.0 to specify a more rut resistant material instead of testing at a higher temperature. Testing for each AASHTO M 332 grade S, H, V or E would be done at the LTPPBind™ regional climate temperature specified. This allows for accurate evaluation of the binder at the expected pavement temperature for the regional climate.

Implementation of MSCR and Transitioning to AASHTO M 332

Recognizing the improved characterization of high temperature performance related properties of asphalt binders provided by the MSCR test and the subsequent AASHTO M 332 PG specifications, the Asphalt Institute (AI) Technical Advisory Committee (TAC) prepared a document for the asphalt industry, users and producers regarding implementation of the MSCR test and specification (Asphalt Institute 2010). The AI document presents the following systematic steps to the implementation of the MSCR test and transition to AASHTO M 332:

- Familiarize with the MSCR Test.
- Familiarize with the AASHTO M 332 Specification.
- Perform Transitional Testing as Necessary.
- Transition Regionally and Uniformly.
- Apply MSCR Percent Recovery as Necessary.
- Eliminate Existing "PG Plus" Tests.

A brief description of each step follows.

Familiarize with the MSCR Test

The only variation in the MSCR test compared to the standard DSR test procedure is the execution of the creep and recovery test. Laboratory practice and procedures identified to effect test results are equally effective with either standard DSR or MSCR testing. As with DSR testing, variability in MSCR testing is minimized with close attention to temperature control, calibration, and proper sample preparation. Regional round-robin testing conducted among users and producers can serve to ensure that the test is being performed properly and is with in accepted testing variability.

Familiarize with the AASHTO M 332 Specification

A major change in the specification is binder performance grade nomenclature. Binders are assigned numerical grades based on the intended use environment, as determined by AASHTO LTPP Bind, followed by a letter designation that identifies expected traffic loading (volume and/or speed) under which the binder is expected to perform. Defined designations are "S" (standard traffic loading), "H" (heavy traffic loading), "V" (very heavy traffic loading), and "E" (extreme traffic loading). The numerical grade also informs the user of the temperature at which grade testing is to be conducted while the letter designation provides information on the criterion for judging the asphalt binder's compliance to the specification. An example of an AASHTO M332 grade is PG 64S-22.

Perform Transitional Testing as Necessary

Agencies lacking experience with the MSCR procedure may choose to conduct comparable transitional testing to become comfortable with the procedure and subsequent results. For transitional testing asphalt binders may be tested according to both AASHTO M 320 and AASHTO M 332 to evaluate agency acceptability of results and comparison of the relationship between the specifications. Valuable information can be gleaned from only three additional tests compared to testing with the current M 320 specification: (1) Original DSR to determine G*/sinδ at the selected LTPPBind™ regional climate temperature; (2) RTFO MSCR at the selected environmental grade temperature to determine J_{nr}, $J_{nr\ diff}$, and MSCR recovery; and (3) PAV DSR to determine G*sinδ at the intermediate temperature based on the environmental grade. To begin testing, technologists typically select the environmental grade temperature specified for the climate in which the binder is expected to be used according to Long-Term Pavement Performance (LTPP) web-based binder selection tool LTPPBind™ 3.1 (FHWA 2005) or as agency specified.

Transition Regionally and Uniformly

Some asphalt binder suppliers market their asphalt products into more than one state from a single location and source. User agencies are encouraged to work with neighboring states, regional user/producer groups and individual suppliers to make a uniform transition to AASHTO M332. Regional uniform transition may aid in preventing potential interruption in supply.

Apply MSCR Percent Recovery as Necessary

The J_{nr} is the parameter that relates to rutting potential in AASHTO M 332. Limits for MSCR percent recovery are not specified, though provisions for agency use are provided by Appendix X. MSCR percent recovery provides an indication of the delayed elastic response of an asphalt binder. A high delayed elastic response is an indication that the asphalt binder has a significant elastic component at a given test temperature. Should the need arise, MSCR percent recovery provides a process to evaluate elastomeric response of binder. A chart is provided to incorporate MSCR percent recovery with J_{nr} in the specification. However, this chart is specifically constructed for use with asphalt binders modified with elastic polymer. Adjustments may be necessary for the evaluation of other modifiers. MSCR percent recovery provides an alternative to "PG Plus" tests such as Elastic Recovery (ER). If the agency does not currently use "PG Plus" tests for modified binder qualification, implementation of MSCR percent recovery limits may not be necessary.

Eliminate Existing "PG Plus" Tests

User agencies may already use "PG Plus" tests, for example ER, Force Ductility, or Toughness and Tenacity. MSCR percent recovery may be effectively used as the replacement for these "PG Plus" tests. It should be noted that a strong relationship between MSCR percent recovery and "PG Plus" tests like ER in most cases is unlikely. MSCR percent recovery may not yield the same results as ER; however, both tests are serving the same purpose of identifying presence of asphalt binder modification. Comparative testing between MSCR percent recovery and other "PG Plus" tests should provide adequate correlation to support necessary MSCR percent recovery specification limits.

Status of Implementation of AASHTO M 332

At the time of this writing, a state-by-state review of published asphalt binder specifications revealed 14 agencies had completed transition to the AASHTO M 332 specification, with an additional 15 implementing AASHTO M 332 for polymer modified binders only. Three agencies had implemented MSCR testing in combination with AASHTO M320 using the MSCR percent recovery to replace "PG Plus" specifications. The remaining 19 agencies, inclusive of the District of Columbia (DDOT), had not implemented AASHTO M 332, however, several are in discussions or efforts of implementation. Figure 7 presents the current status of implementation of AASHTO M 332 and the MSCR specification parameter with states grouped according to regional user producer groups:

- **NEAUPG – North East Asphalt User/Producer Group**
- **NCAUPG – North Central Asphalt User/Producer Group**
- **PCCAS – Pacific Coast Conference on**

Asphalt Specifications

- **RMAUPG – Rocky Mountain Asphalt User/Producer Group**
- **SEAUPG – Southeastern Asphalt User/Producer Group**

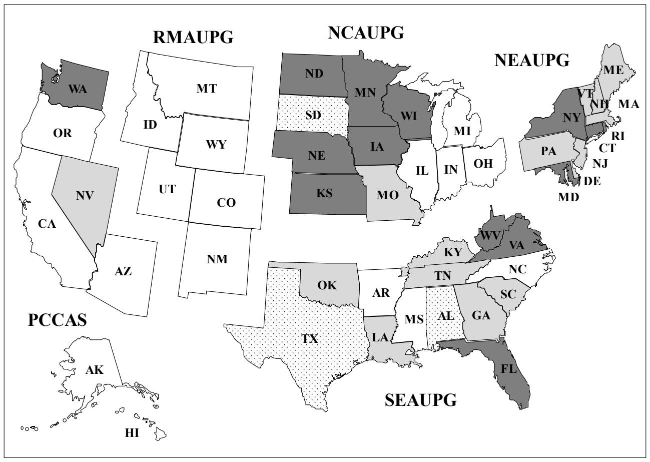

Figure 7. Implementation Status of AASHTO M 332 and the MSCR Specification Parameter.

- Fourteen States Using AASHTO M332 are represented by dark shading.
  - CT, FL, IA, KS, MD, MN, NE, ND, NY, RI, VA, WA, WI, WV
- Fifteen States Using AASHTO M332 for PMB only are represented by light shading.
  - DE, GA, KY, LA, MA, ME, MO, NH, NJ, NV, OK, PA, SC, TN, VT
- Three States Using AASHTO M320 with MSCR percent recovery as a Plus test are represented by pattern fill.
  - AL, SD, TX
- Eighteen States Using AASHTO M320 and other PG Plus tests are not shaded or filled.
  - AK, AR, AZ, CA, CO, HI, ID, IL, IN, MI, MS, MT, NC, NM, OH, OR, UT, WY.

For comparison purposes, Figure 8 presents the status of implementation of AASHTO M 332 and the MSCR specification parameter in the Canadian provinces based on presentations at the 2019 Canadian Technical Asphalt Association (CTAA) annual meeting. Alberta, New Brunswick, Nova Scotia, Prince Edward Island, and Quebec are all using AASHTO M 332 for binders. Prince Edward Island uses it for PMB only. Manitoba, Ontario, and Saskatchewan use AASHTO M 320 while British Columbia continues to use penetration specifications.

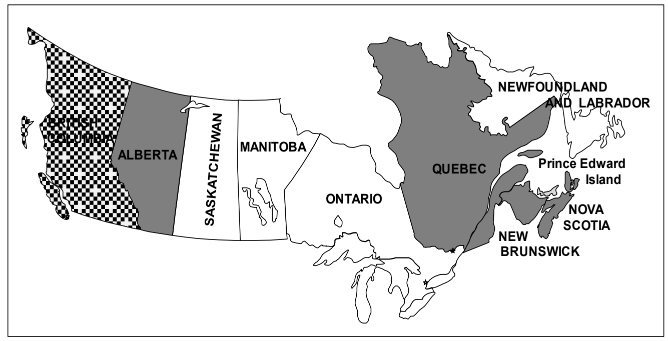

Figure 8. Implementation Status of AASHTO M 332 and the MSCR Specification Parameter in the Canadian Provinces.

Conclusion

The SHRP research and advent of the Superpave PG binder specification, AASHTO M320 provided the U.S. highway industry with an improvement in the way asphalt binders are specified. New testing equipment has provided more information with respect to physical and engineering properties of asphalt binders than was available in the past. The complex modulus and phase angle from DSR testing provide direct information on the mechanical properties of the binder. This information is used to access the physical properties of the asphalt binder to determine how it is expected react under loading.

The MSCR test (AASHTO T 350) and specification (AASHTO M 332) have provided information concerning the performance characteristics of asphalt binders not addressed by AASHTO M 320. Information from the creep testing of the binder has helped to better access the rutting resistance of pavements containing modified asphalt binders. This information has assisted in explaining how the pavement recovers after loading to resist rutting.

Until all the components of AASHTO M 332 have been implemented, highway agencies are limited to using some engineering judgment in specifying modified asphalt binders. Typically, this has led to using PG plus specification tests or in some cases using AASHTO M 332 MSCR percent recovery as a PG plus specification limit. This technical brief has presented an update and identified steps that could be followed to facilitate implementation of AASHTO M 332. AASHTO M 332 uses information collected using existing Superpave binder tests with addition of the MSCR test and related outputs, thus eliminating the need to run additional tests (PG Plus Tests) to differentiate neat binders from modified binders. Additionally, and of greater importance, MSCR testing is performance related, opposed to using more empirical tests normally employed to evaluate modified binders.

References

1. AASHTO M 320, American Association of State Highway and Transportation Officials (AASHTO), "Standard Specification for Performance-Graded Asphalt Binder," 2017.
2. AASHTO M 323, American Association of State Highway and Transportation Officials (AASHTO), "Standard Specification for Superpave Volumetric Mix Design," 2017.
3. AASHTO M 332, American Association of State Highway and Transportation Officials (AASHTO), "Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep and Recovery (MSCR) Test," 2019.
4. AASHTO R 92, American Association of State Highway and Transportation Officials (AASHTO), "Standard Practice for Evaluating the Elastic Behavior of Asphalt Using the Multiple Stress Creep Recovery (MSCR) Test," 2018.
5. AASHTO T 313, American Association of State Highway and Transportation Officials (AASHTO), "Standard Method of Test for Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)," 2019.
6. AASHTO T 315, American Association of State Highway and Transportation Officials (AASHTO), "Standard Method of Test for Determining the Rheological Properties of Asphalt Binders Using a Dynamic Shear Rheometer (DSR)," 2017.
7. AASHTO T 350, American Association of State Highway and Transportation Officials (AASHTO), "Standard Method of Test for Multiple Stress Creep Recovery (MSCR) Test of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)," 2018.
8. Asphalt Institute (AI), Technical Advisory Committee, "Implementation of the Multiple Stress Creep and Recovery Test and Specification," Asphalt Institute Guidance Document, April 2010.
9. Baumgardner, G.L., Reinke, G., Anderson, D.A., Rowe, G.M.: Laboratory Evaluation: Wax Additives in Warm-Mix Asphalt Binders, Report from FHWA Binder Expert Task Group and Warm Mix Asphalt Technical Working Group, Report submitted to Engineering & Software Consultants, Inc. and Federal Highways Administration (2009).
10. Crawley, A.B., "HMA Polymer Modifiers Field Trial, Project No. IM-055-3(70) I-55 between Grenada and Tillatobia, Grenada and Yalabusha Counties, MDOT memo, February 15, 1996.
11. D'Angelo, J.A., and R. Dongre. "Superpave Binder Specifications and Their Performance Relationship to Modified Binders." In Proceedings of the Forty-Seventh Annual Conference of the Canadian Technical Asphalt Association (CTAA): Calgary, Alberta. 2002.
12. D'Angelo, John, Robert Kluttz, Raj N. Dongre, Keith Stephens, and Ludo Zanzotto. "Revision of the Superpave High Temperature Binder Specification: The Multiple Stress Creep Recovery Test (with discussion)." Journal of the Association of Asphalt Paving Technologists 76 (2007).
13. D'Angelo, J.A., and R. Dongre. "Practical use of the MSCR Test: Characterization of SBS Dispersion and Other Additives in PMA Binders." Journal of Transportation Research Record 2126 (2009): 73-82.
14. D'Angelo, J.A., "MSCR, What is Jnr diff and What Does it Mean," Asphalt Magazine, Fall 2018, Vol. 33 No. 3, pg. 36.

15. Federal Highway Administration (FHWA), LTPPBind™, Version 3.1 Beta, Federal Highway Administration, Washington, DC, 2005.
16. Federal Highway Administration (FHWA), "Long-Term Pavement Performance Bind Online User Guide," Publication No. FHWA-HRT-17-010, October 2017.
17. Federal Highway Administration (FHWA), "The Multiple-Stress Creep Recovery (MSCR) Procedure," Tech Brief, FHWA-HIF-11-038 April 2011.
18. 18. Rowe, G. M., G. L. Baumgardner, G. Reinke, and D. A. Anderson. "Wax Additives in Warm-Mix Asphalt Binders and Performance in the Multi-Stress Creep and Recovery Test (MSCR)." In Paper submitted to the 5th Eurasphalt & Eurobitume Congress, Istanbul. 2012.