Standard Method of Test for

Estimating Effect of RAP and RAS on Blended Binder Performance Grade without Binder Extraction

AASHTO Designation: T XXX-12

1. SCOPE

1.1 This test method covers the use of mortar and binder samples tested in the Bending Beam Rheometer and Dynamic Shear Rheometer to quantify the effect of RAP and RAS binder on the fresh binder continuous grade profile, allowing for an estimation of blended binder properties at critical pavement temperatures. The testing procedure produces a RAP/RAS binder-fresh binder continuous grade change rate, allowing for the estimation of mixture performance grade given any amount of RAP and RAS binder replacement within the mixture.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1 *ASTM Standards:*

ASTM D 7175-08 – Standard Test Method for Determine the Rheological Properties of Asphalt Binder Using the Dynamic Shear Rheometer.

ASTM D 6648-08 – Standard Test Method for Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer.

ASTM D6307 – Standard Test Method for Asphalt Contentof Hot Mix Asphalt by Ignition Method.

ASTM D8 – Standard Terminology Relating to Materials for Roads and Pavements

2.2 *AASHTO Standards:*

3. TERMINOLOGY

3.1 *General Definitions:*

3.1.1 General definitions of terms used in this practice may be found in Terminology ASTM D 8 determined from common English usage, or combinations of both.

3.2 Procedural Definitions

3.2.1 *Binder Performance Grade Change Rate:* Change in blended binder continuous grade per the addition of one percent binder replacement in the mortar [°C/% RAP(S) binder replacement]. Also known as *Rate of Grade Improvement*.

3.2.2 *Binder Replacement*: The weight percentage of reclaimed/recycled binder present in the mortar material in substitution for an equal weight percentage of fresh binder.

3.2.3 *Blended Binder:* The effective asphalt binder (fresh binder blended with RAP(S) binder) in the mortar material after mortar preparation. Blending does not need to be present to test the mortar materials in the proposed procedure, and may not be if the mortar preparation is completed at low mixing temperatures, or the RAP(S) material is heavily oxidized.

3.2.4 *Burned Aggregates*: RAP or RAS material burned in the ignition oven according to ASTM D6307-05 and is free from binder material.

3.2.5 *Continuous Grade*: The temperature at which the associated Superpave PG limiting specification parameter is reached at either low, intermediate, or high testing temperature ranges. Always reported as the most conservative value if multiple specification parameters are given. Also known as *True Grade*.

3.2.6 *Fresh Binder*: Asphalt binder material selected for the mortar preparation and subsequent characterization, either unmodified or modified. Can be artificially aged for specific characterization purposes, i.e. RTFO aged fresh binder, PAV aged fresh binder etc. Also known as *Virgin Binder*.

3.2.7 *Mortar*: Void-less mixture of R_{100} Aggregates and fresh binder.

3.2.8 *R100 Aggregates*: Either RAP or RAS, burned or unburned, passing sieve # 50 (300 µm) and retained on sieve # 100 (150 µm). Passing sieve #100 are discarded.

3.2.9 *RAP*: Recycled (Reclaimed) Asphalt Pavement.

3.2.10 *RAS*: Recycled (Reclaimed) Asphalt Shingles.

3.2.11 *Total Binder Content*: Weight percentage of binder (fresh binder + RAP/RAS binder) in mortar material.

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4. SUMMARY OF METHOD

4.1 Three samples are tested at low, intermediate and high critical Superpave temperatures. These samples include one fresh binder and two void-less mortar samples; the mortars are comprised of the same fresh binder and a single gradation aggregate source. The two mortar samples are prepared with identical gradation and identical total asphalt content using the same constituents, but one mortar sample contains a percentage of reclaimed binder (replacing an identical percentage of fresh binder), therefore any difference in properties between the mortar samples is attributed to the percentage of reclaimed binder. If the properties of the fresh binder used for making the mortar samples are known, then the change in properties of the fresh binder due to blending with the reclaimed binder can be isolated.

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5. SIGNIFICANCE AND USE

5.1 This test method is intended to provide an estimate of fresh binder performance grade change rate in terms of binder replacement by reclaimed asphalt materials (RAP and/or RAS) in a mixture. The procedure eliminates the need, and variability associated with, chemical extraction and recovery; the reclaimed binder is characterized without modification. The procedural results are blind to RAP source, RAS source and fresh binder source, and binder modification. This test method uses standard methods of binder specification at low, intermediate, and high critical pavement temperatures, allowing for a full characterization profile of the reclaimed – fresh binder properties. The procedure can be used to optimize the amount of binder replacement allowed to meet a desired performance grade, or likewise determine the resulting blended binder performance grade produced by a known binder replacement.

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6. SAMPLE PREPARATION

6.1 The user should select a fresh binder source as well as a source of RAP, RAS, or a RAP/RAS material blend for testing. The fresh binder and recycled material source should match the expected materials for field use.

6.2 RAP or RAS material should be dried and sieved. Materials passing sieve #50 and retained on #100 sieve (R_{100}) are collected (P_{100} material is discarded). At least 500 g of R_{100} material should be collected. The R_{100} material is then split into two equal batches:

6.2.1 Batch 1: Burn samples of the RAP or RAS in the ignition oven to estimate the RAP binder content of the R_{100} material following ASTM D6307-05, and to procure the RAP or RAS R_{100} aggregates.

6.2.2 Batch 2: Mix approximately 150 g of the R_{100} material from (6.2) with RTFO aged fresh binder to create RTFO-A mortar. The amount of RTFO binder required will depend on the workability of the mortar. The mortar should be workable enough to cast BBR beams. Total binder content (RAP binder + RTFO binder) of 30 percent by weight is recommended as a starting point for the mortar sample. Continue to add RTFO binder until the desired workability is achieved. The desired workability is the workability of the mortar that allows for BBR and DSR samples to be cast free from air voids, and generally requires total mortar asphalt content to be greater than 30 percent by weight.

6.3 Burned aggregates from (6.2.1) are mixed with RTFO aged fresh binder at the same *total* binder content as the RTFO-A mortar prepared in (6.2.2). Approximately 150 g of the burned aggregates makes a good starting point. This mortar is denoted as RTFO-B mortar.

6.4 Age the RTFO-B (from 6.3) and RTFO-A (from 6.2.2) mortars in the Pressure Aging Vessel (PAV) for 24 hours at 100 °C. The amount of mortar in each PAV pan is determined so that 50 grams total of binder is present in the pan. For example, if the total binder content of the mortars is 40 percent, the amount of mortar in each PAV pan will be 50g / (0.40 binder content) = 125 g mortar.

6.5 The RTFO aged fresh binder is also PAV aged according to the standard PAV procedure.

6.6 The PAV-B and PAV-A mortar (from 6.3), along with the PAV aged fresh binder (from 6.5) are cast into separate BBR beams and tested at two target low temperatures.

6.7 (6.2.2) and (6.3) will be repeated using unaged fresh binder in place of RTFO fresh binder to create fresh-A and fresh-B mortar. These samples will only be used for DSR testing at high temperatures, hence require less material to mix (approximately 40g of R_{100}). These mortars can be mixed at the same total binder content used in steps (6.2.2) and (6.3), but may be mixed at a new total binder content if desired.

The test samples required for a complete analysis procedure are summarized in Table 1.

Table 1: Required Test Specimens for Complete Performance Grade Analysis

Low Temperature: BBR		**Intermediate Temperature: DSR**		**High Temperature: DSR**	
Binder Samples	Mortar Samples	Binder Samples	Mortar Samples	Binder Samples	Mortar Samples
PAV Binder	PAV A	PAV Binder	PAV A	Fresh	Fresh A
	PAV B		PAV B		Fresh B
				RTFO	RTFO A
					RTFO B

The following graphic illustrates the mortar preparation process and the distinction between the A-mortar and B-Mortar.

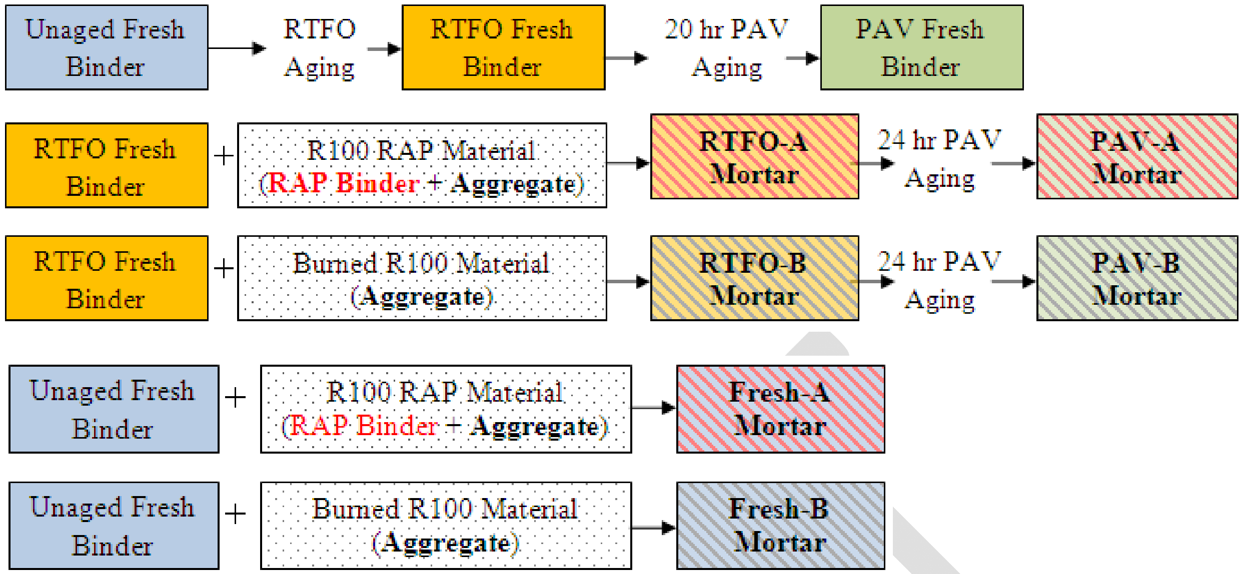

Figure 1: Mortar preparation procedure.

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7. TESTING PROCEDURE

7.1 *Low Temperature*. PAV aged fresh binder and PAV aged mortar samples will be tested in the BBR using standard BBR specimen geometry. The BBR test will be carried out at two temperatures as determined by the fresh binder grade and using a load proportional to the testing temperature. Generally, the PG grade and plus one grade is selected for testing. For example a PG 64 - 22 binder would be tested at -6 °C and -12 °C for low temperature analysis. The testing loads are adjusted using the air bearing to allow for adequate deflection in the mortar samples. Table 2 displays the appropriate loading for the test specimens.

Table 2: Bending Beam Rheometer Test Loads in mN.

Test Temperature [C]	PAV Binder	PAV Mortar
0	980	980
-6	980	1980
-12	980	2980
-18	980	3980
-24	980	4980

7.2 The required outputs for the procedure calculations are the 60-second stiffness and the 60-second m-value for the PAV aged fresh binder and PAV aged mortar. This is identical to the standard Superpave BBR grading method.

7.3 *Intermediate Temperature*. PAV aged fresh binder and PAV aged mortar samples will be tested in the DSR using standard Superpave intermediate temperature DSR specimen geometry. The test procedure at intermediate temperature follows a standard binder PG test at two temperatures. The testing temperatures are determined to be the corresponding fresh binder intermediate temperature grade and plus one grade. For example, with a PG 64-22 fresh binder the testing temperatures would be 25 °C and 28 °C.

7.4 The required outputs for the procedural calculations at intermediate temperature are the fatigue parameter G*sin(δ) at 10 radians/second for the PAV aged fresh binder and PAV aged mortar. This is identical to the standard Superpave intermediate temperature DSR grading method.

7.5 *High Temperature*. RTFO aged and unaged fresh binder as well as RTFO aged and fresh mortar samples will be tested in the DSR using a modified Superpave high temperature DSR testing procedure. The test procedure for the unaged fresh and RTFO aged fresh binder follows a standard binder PG test at two temperatures. The mortar samples are tested at the same two temperatures but require a 2 mm gap setting. All other conditions remain unchanged between the binder and mortar samples. The testing temperatures are determined to be the corresponding fresh binder high temperature grade and plus one grade. For example, with a PG 64-22 fresh binder the testing temperatures would be 64 °C and 70 °C.

7.6 The required outputs for the procedural calculations at high temperatures are the rutting parameter G*/sin(δ) at 10 radians/second for the RTFO aged and unaged fresh binder as well as RTFO aged and fresh mortar samples. This is identical to the standard Superpave high temperature DSR grading method.

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8. CALCULATION AND INTERPRETATION OF RESULTS

8.1 *Data Analysis*. The following calculations are performed on the test data from (7) to provide an estimate of fresh binder performance grade change rate in terms of binder replacement by the reclaimed asphalt materials.

8.1.1 *Low Temperature*. The low temperature continuous grade of the PAV aged fresh binder is calculated as the temperature at which the limiting low temperature parameter value is reached first. For example a PG 64 - 22 binder would be tested at T_2=-6 °C and T_1=-12 °C.The limiting parameter values at low temperature are defined as the maximum creep stiffness of 300 MPa or a minimum m-value of 0.300. This is demonstrated in the following graphic.

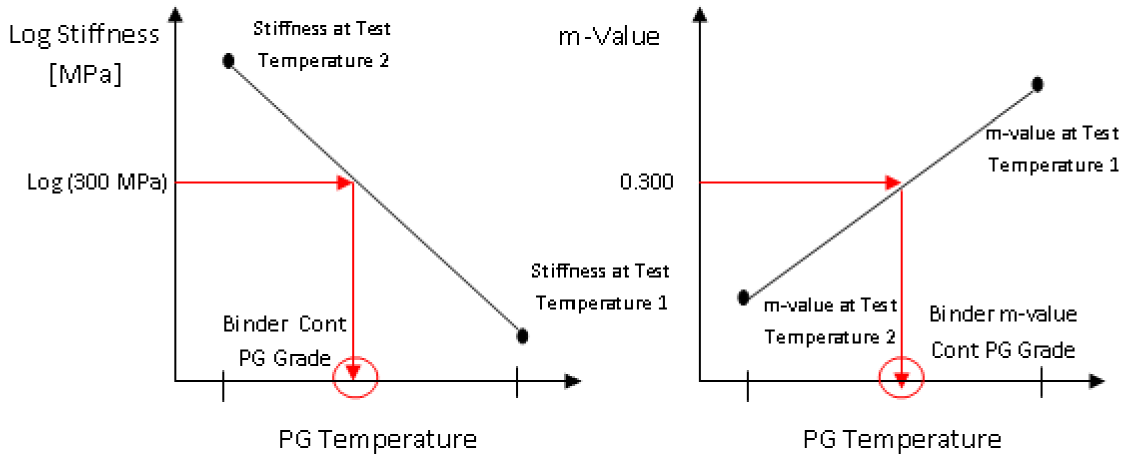

Figure 2: Low temperature continuous performance grade procedure for asphalt binder. The continuous grade is taken as the higher temperature between stiffness and m-value.

The PAV aged mortar testing results are then used to determine the effect of blending the reclaimed RAP or RAS binder with the fresh binder on the blended binder stiffness and m-value. The logarithm of the PAV-A stiffness at 60 seconds is divided by the logarithm of the PAV-B stiffness at 60 seconds to determine the stiffness "shift" value δ_S. This is completed for each of the two test temperatures and the stiffness shift values are averaged for the two temperatures. The PAV-A m-value at 60 seconds is divided by the PAV-B m-value at 60 seconds to determine the m-value "shift" value δ_m. . This is completed for each of the two test temperatures and the m-value shift values are averaged for the two temperatures. This process is demonstrated below:

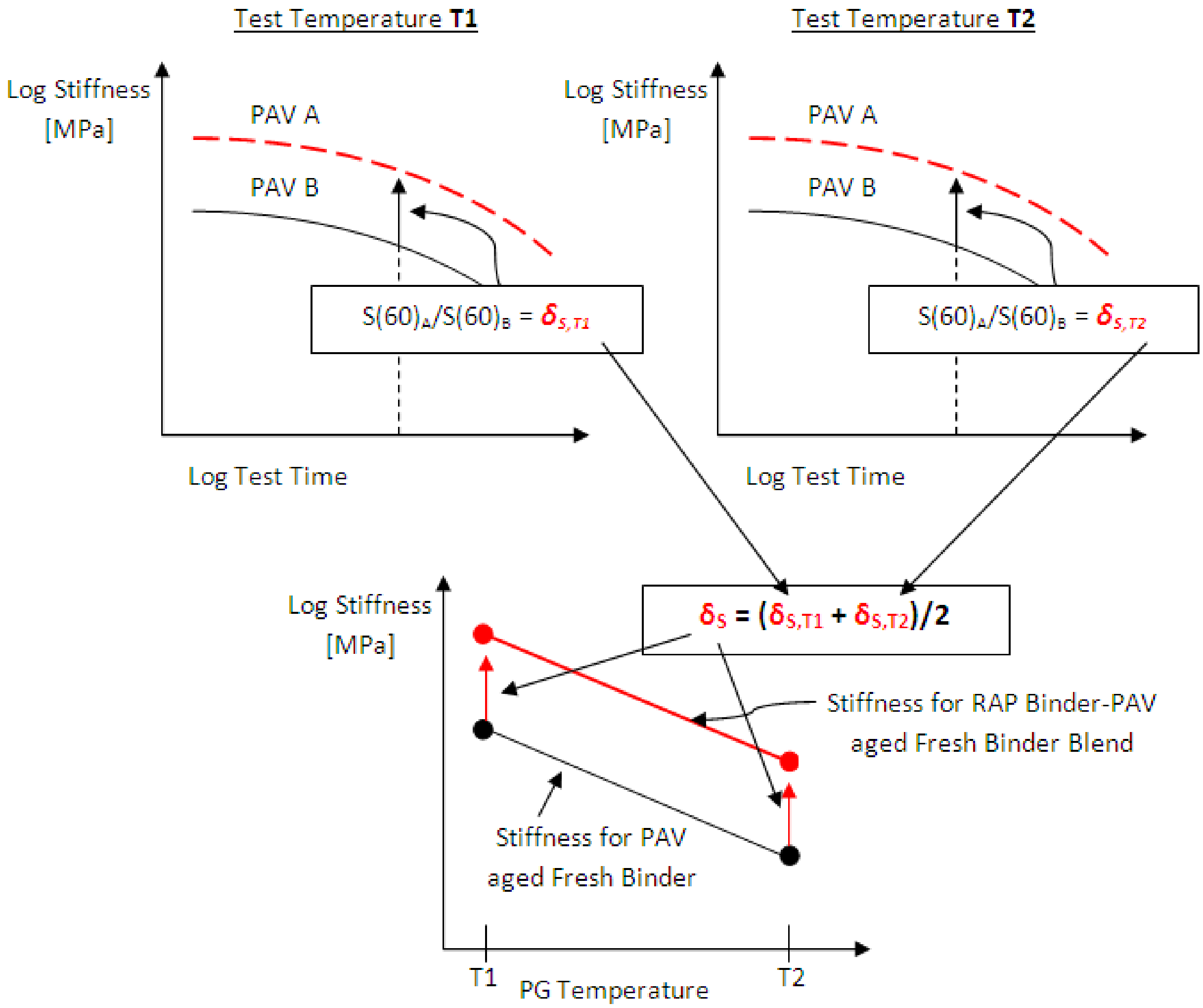

Figure 3: Determination and application of the low temperature shift factor δ_S to PAV aged fresh binder continuous grade profile.

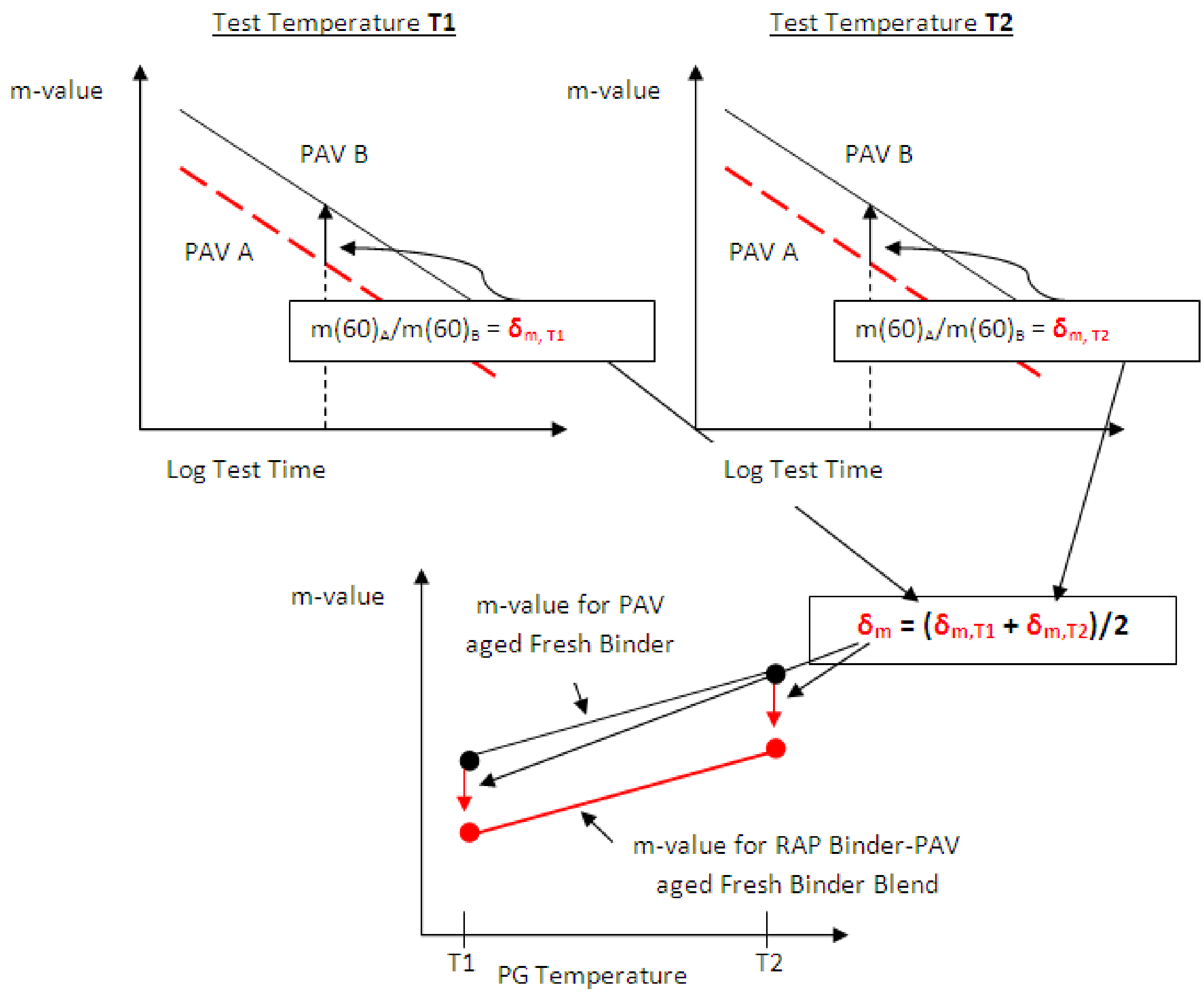

Figure 3: Determination and application of the low temperature shift factor δ_m to PAV aged fresh binder continuous grade profile.

The appropriate shift value is applied to the PAV aged fresh binder low temperature parameter values by multiplying the PAV aged fresh binder parameter value by the appropriate shift value. For example, the PAV aged fresh binder stiffness at 60 seconds is multiplied by δ_S at each test temperature. Likewise, the PAV aged fresh binder m-value at 60 seconds is multiplied by δ_m at each test temperature. The result is the estimated low temperature blended binder stiffness at the two testing temperatures and the estimated low temperature blended binder m-value at the two testing temperatures, shown as the red continuous grade profiles in the previous figures. The estimated blended binder stiffness and m-value parameter values at each temperature are then used to calculate the estimated blended binder low temperature continuous grade in the same fashion as the PAV aged fresh binder. The estimated low temperature continuous grade of the blended binder should be higher than the PAV aged fresh binder low temperature continuous grade. From the estimated blended binder continuous grade and PAV aged fresh binder continuous grade, the grade change rate for the reclaimed binder can be calculated as

$$\frac{(Estimated\ C.G.-PAV\ Binder\ C.G.)}{AC_{RAP}} = Grade\ Change\ Rate$$

Where,

Estimated C.G.: Estimated blended binder continuous grade [°C]

PAV Binder C.G.: PAV aged fresh binder continuous grade [°C]

AC_{RAP}: Percent binder replacement [%]

Grade Change Rate: Rate of fresh binder grade improvement per percent binder replaced. [°C/% replacement]

8.1.2 *Intermediate Temperature*. The intermediate temperature continuous grade of the PAV aged fresh binder is calculated as the temperature at which the limiting fatigue parameter value is reached first. The limiting parameter values at intermediate temperature is defined as a maximum fatigue parameter G*sin(δ) value of 5000 kPa.

The PAV aged mortar testing results are then used to determine the effect of blending the reclaimed RAP or RAS binder with the fresh binder on the blended binder fatigue parameter G*sin(δ) in an analogous method to the low temperature analysis. The logarithm of the PAV-A mortar G*sin(δ) at 10 radians/second is divided by the logarithm of the PAV-B mortar G*sin(δ) at 10 radians/second to determine the G*sin(δ) "shift" value. This is completed for each of the two test temperatures and the G*sin(δ) shift value are averaged for the two temperatures.

The intermediate temperature shift value is then applied to the PAV aged fresh binder fatigue parameter values by multiplying the PAV aged fresh binder parameter value by the appropriate shift value, similar to (8.2.1). The result is the estimated blended binder G*sin(δ) at the two testing temperatures. The estimated blended binder G*sin(δ) parameter values at each temperature are then used to calculate the estimated blended binder continuous grade in the same fashion as the PAV aged fresh binder. The estimated continuous grade of the blended binder should be higher than the PAV aged fresh binder continuous grade. From the estimated blended binder continuous grade and PAV aged fresh binder continuous grade, the grade change rate for the reclaimed binder can be calculated at intermediate temperature in the same fashion as (8.1.1).

8.1.3 *High Temperature*. The high temperature continuous grade is defined as the temperature at which either the RTFO aged fresh binder or unaged fresh binder reaches the corresponding limiting parameter value first. The limiting parameter value at high temperature for the RTFO aged fresh binder is a minimum parameter G*/sin(δ) value of 2.20 kPa. The limiting parameter value at high temperature for the unaged fresh binder is a minimum parameter G*/sin(δ) value of 1.00 kPa.

The RTFO aged and fresh mortar testing results are then used to determine the effect of blending the reclaimed RAP or RAS binder with the fresh binder on the blended binder high temperature performance parameter G*/sin(δ) in the same fashion as the intermediate temperature analysis . The logarithm of the RTFO-A mortar G*/sin(δ) at 10 radians/second is divided by the logarithm of the RTFO-B mortar G*/sin(δ) at 10 radians/second to determine the G*/sin(δ) "shift" value. The same calculation is completed for the fresh mortars. This is completed for each of the two test temperatures and the G*/sin(δ) shift value are averaged for the two temperatures.

8.1.4 The appropriate shift value is then applied to the fresh or RTFO aged fresh binder high temperature performance parameter value by multiplying the fresh or RTFO aged fresh binder high temperature performance parameter by the appropriate shift value, similar to (8.1.1). The result is the estimated blended binder G*/sin(δ) at the two testing temperatures for RTFO aged material and estimated blended binder G*/sin(δ) at the two testing temperatures for unaged binder material . The estimated RTFO and fresh blended binder G*/sin(δ) is then used to calculate the estimated blended binder continuous grade in the same fashion as the typical high temperature continuous grading approach. The high temperature blended binder continuous grade is defined as the temperature at which either the RTFO or fresh blended binder G*/sin(δ) reaches the corresponding limiting parameter value first. The limiting parameter values remain unchanged; the RTFO aged minimum rutting parameter G*/sin(δ) value is 2.20 kPa, while the limiting parameter value for unaged fresh binder is a minimum G*/sin(δ) value of 1.00 kPa. The estimated continuous grade of the blended binder should be higher than the fresh binder continuous grade. From the estimated blended binder continuous grade and PAV aged fresh binder continuous grade, the grade change rate for the reclaimed binder can be calculated at intermediate temperature in the same fashion as (8.1.1).

9. REPORT

10. PRECISION AND BIAS

10.1 Adherence to precision and bias statements of ASTM D 6648-08 – Standard Test Method for Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer and ASTM D 7175-08 – Standard Test Method for Determine the Rheological Properties of Asphalt Binder Using the Dynamic Shear Rheometer has been found to be acceptable. Ongoing testing is being completed to further characterize precision and bias of the proposed procedure.

APPENDIX

X1. EXAMPLE MORTAR MIXTURE DESIGN CALCULATIONS

X1.1 *Mortar Mix Design*. The following calculations are an example of mortar mixture design calculations performed to determine the appropriate material proportions for the mortar samples. However, other methods of design are possible.

RTFO-A mortar samples are prepared according to (6.2.2). The following equations are valid for RAS materials and RAP/RAS material blends, with the only adjustment being the R_{100} asphalt content. The mortar total asphalt content AC_{total} and percent binder replacement AC_{RAP} are calculated from the following two equations:

$$Mortar\ Total\ Asphalt\ Content: AC_{total-A} = \left[\frac{(RAP_S * R100_{AC}) + RTFO}{RAP_S + RTFO}\right] * 100$$

$$Reclaimed\ Binder\ Replacement: AC_{RAP} = \left[\frac{RAP_S * R100_{AC}}{(RAP_S * R100_{AC}) + RTFO}\right] * 100$$

Where,
$AC_{total\text{-}SRAP}$: *RTFO-A Mortar total asphalt content [%]*
AC_{RAP}: *Percent RAP binder replacement [%]*
RAP_S: *Sieved R_{100} RAP material quantity [g]*
$R100_{AC}$: *R100 RAP asphalt content [%]*
RTFO: RTFO aged fresh binder quantity [g]

RTFO-B mortar samples are prepared according to (6.3). Here, the user will only control the quantity of burned R_{100} material, as the binder quantity is governed by AC_{total} from above. The RTFO-A and RTFO-B mortars have the same total binder content; the amount of RTFO aged fresh binder required in the RTFO-B mortar for this to be true is then:

$$RTFO = \frac{AC_{total-A} * RAP_B}{1 - AC_{total-A}}$$

Where,
RAP_B: *Burned R_{100} RAP material [g]*

The RTFO-B total binder content $AC_{total\text{-}B}$ is then be expressed as

$$AC_{total-B} = \left(\frac{RTFO}{RAP_B + RTFO}\right) * 100$$

And

$$AC_{total-B} = AC_{total-A}$$

Note that for the previous equation to be true, the quantity of RTFO aged fresh binder required for the RTFO-RRAP mortar will be greater than the quantity used in the RTFO-SRAP mortar as the RTFO-SRAP contains RTFO aged fresh binder along with RAP binder whereas the RTFO-RRAP only contains RTFO aged fresh binder.

The above preparation formulae are also applicable to Fresh-mortar preparation, where RTFO aged fresh binder is replaced with unaged fresh binder. If the user desires to have the total asphalt content of the fresh mortars be equal to the total asphalt content of the RTFO mortars, the following equations are used to calculate the amount of fresh binder required to prepare the fresh mortars:

$$Fresh_A = \left[\frac{(AC_{total-A} * RAP_S) - (RAP_S * R100_{AC})}{1 - AC_{total-A}}\right]$$

And

$$Fresh_R = \left(\frac{AC_{total-A} * RAP_B}{1 - AC_{total-A}}\right)$$

Where
$Fresh_A$: Required unaged fresh binder for Fresh-A mortar [g]
$Fresh_B$: Required unaged fresh binder for Fresh-B mortar [g]