Appendix I. DRAFT AASHTO STANDARD PRACTICE

Proposed Standard Practice for

Characterization of Asphalt Mixtures with High Recycled Materials Contents and Recycling Agents

AASHTO Designation: R XX-XX

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1. SCOPE

1.1 This practice describes practical tools to evaluate the effectiveness of recycling agents (rejuvenators) initially and with aging for hot mix asphalt mixtures with large quantities of reclaimed asphalt pavement (RAP) and/or recycled asphalt shingles (RAS) (high recycled materials contents). This practice also describes component materials selection, proportioning guidelines for recycled materials, and recycling agent dose selection.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to its use.*

1.3 *Rejuvenation mechanisms of RAP/RAS binders and chemical changes associated with aging are a function of recycling agent type. Different recycling agent types have different chemical composition and may respond differently to long-term aging in rejuvenated binder blends and corresponding hot mix asphalt mixtures. Thus, selection of recycling agent type is included in the scope of this standard practice with respect to characterization of rejuvenated binder blends and hot mix asphalt mixtures.*

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2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards*

- T 164, Quantitative Extraction of Asphalt Binder from Hot-Mix Asphalt (HMA)
- R 30, Mixture Conditioning of Hot-Mix Asphalt (HMA)
- T 315-12, Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)

- T 313-12, Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)
- M 320-16, Performance-Graded Asphalt Binder
- T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)
- R 28, Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
- T 324-17, Hamburg Wheel-Track Testing of Compacted Asphalt Mixtures
- T 342-15, Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures
- TP 124-16, Determining the Fracture Potential of Asphalt Mixtures Using Semicircular Bend Geometry (SCB) at Intermediate Temperature
- TP 125-16, Determining the Flexural Creep Stiffness of Asphalt Mixtures Using the Bending Beam Rheometer (BBR)

2.2 *ASTM Standards*

- D5404, Standard Practice for Recovery of Asphalt from Solution Using the Rotary Evaporator
- WK60626, Determining Thermal Cracking Properties of Asphalt Mixtures through Measurement of Thermally Induced Stress and Strain

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3. TERMINOLOGY

3.1 ΔT_c, the difference in continuous low-temperature performance grade (PGL) temperature for stiffness and relaxation properties in the BBR (i.e., the critical temperature when S equals 300 MPa minus the critical temperature when m-value equals 0.30).

3.2 *Base binder,* for the purposes of this specification, shall mean new (virgin) performance-graded asphalt binder to be used in the new hot mix asphalt.

3.3 *Cracking resistance index—*CRI_{ENV}, an index intended to characterize the cracking resistance of hot mix asphalt mixtures determined through calculations of measured thermal stress and thermal strain and adjusted for in-situ environment.

3.4 *Crossover temperature—*$T_{\delta=45°}$, rheological index calculated from DSR master curve obtained experimentally from strain-controlled oscillatory measurements at 10 rad/s. $T_{\delta=45°}$ is the temperature at which the storage modulus (G') is equal to the loss modulus (G") and the phase angle is 45 degrees.

3.5 *Dynamic modulus—*$|E^*|$, the absolute value of the complex modulus calculated by dividing the peak-to-peak stress by the peak-to-peak strain for a material subjected to a sinusoidal loading.

3.6 *Flexibility index—FI,* an index intended to characterize the damage resistance of hot mix asphalt mixtures and calculated based on the fracture energy and the slope at the inflection point of the post-peak load versus displacement curve per AASHTO TP 124.

3.7 *Glover-Rowe parameter—G-R,* rheological index for binders and binder blends that combines the effect of stiffness (shear complex modulus |G*|) and embrittlement (phase angle δ) at intermediate temperatures. A DSR master curve is obtained experimentally from strain-controlled oscillatory measurements in the linear-viscoelastic region, and G-R is calculated at 15°C and 0.005 rad/s, where $G\text{-}R = |G^*| \cos^2 \delta / \sin \delta$.

3.8 *High-temperature performance grade—PGH.*

3.9 *High-temperature performance grade for the target climate—*PGH_{Target}*,* the target binder is the one required to satisfy climate and traffic requirements per agency specifications.

3.10 *Low-temperature performance grade—PGL.*

3.11 *Manufactured waste asphalt shingles—MWAS,* rejected asphalt shingles or shingle tabs that are discarded in the manufacturing process of new asphalt shingles.

3.12 *Mixture flexural creep stiffness—*S_m*,* creep stiffness obtained by fitting a second order polynomial to the logarithm of the measured stiffness, from 8.0 to 1,000 seconds, as a function of the logarithm of time per AASHTO TP 125.

3.13 *Mixture Glover-Rowe parameter—*$G\text{-}R_m$*,* rheological index for hot mix asphalt mixture that combines the effect of stiffness (|E*|) and embrittlement (δ) at 20°C and 5 Hz per AASHTO T 342, where $G\text{-}R_m = |E^*| \cos^2 \delta / \sin \delta$.

3.14 *Mixture relaxation rate—*$m\text{-}value_m$*,* absolute value of the slope of the logarithm of the estimated creep stiffness curves versus the logarithm of the time per AASHTO TP 125.

3.15 $N_{12.5}$*,* number of load cycles to reach 12.5-mm rut depth by asphalt pavement analyzer (APA) and Hamburg wheel tracking test (HWTT) per AASHTO TP 324.

3.16 *Phase angle—Ø*, the angle in degrees between a sinusoidally applied stress and the resulting strain in a controlled-stress test.

3.17 *Reclaimed asphalt pavement—RAP,* removed and/or processed pavement materials containing asphalt binder and aggregate.

3.18 *Recycled asphalt shingles—RAS,* manufactured shingle waste or post-consumer asphalt shingle that has been processed into a recyclable material.

3.19 *Recycled binder blend,* for the purposes of this specification, shall mean the mixture of base binder and RAP/RAS binders.

3.20 *Recycled binder ratio—RBR,* percentage of recycled binder from RAP and/or RAS by weight with respect to the total binder by weight, determined as the sum of the RAP binder ratio *(RAP_{BR})* and the RAS binder ratio *(RAS_{BR})*.

3.21 *Recycling agent,* additive with chemical and physical characteristics designed to restore the rheological properties of aged asphalt binders in recycled asphalt mixtures. Recycling agents are often called "rejuvenators."

3.22 *Recycling agent dose,* the recycling agent percent by mass of total binder in the asphalt mixture, including base binder and RAP/RAS binders.

3.23 *Tear-off asphalt shingles—TOAS,* asphalt shingles that are removed from the roofs of existing structures when the new roofs are being installed. Tear-off asphalt shingles are sometimes called "post-consumer shingles."

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4. SUMMARY OF PRACTICE

4.1 This practice describes the laboratory experiments and analysis needed to select the recycling agent dose and evaluate the effectiveness of the recycling agent, initially and with aging, for hot mix asphalt mixtures with high RAP and RAS contents.

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5. SIGNIFICANCE AND USE

5.1 Increasing the quantity of recycled materials in hot mix asphalt mixtures provides economic and environmental benefits. However, this practice poses technical challenges in terms of hot mix asphalt mixture production, compaction, and long-term performance. To meet these challenges, appropriate mixture component selection, proportioning adjustments, and/or modifications such as employing a recycling agent at an appropriate dose are recommended.

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6. HAZARDS

6.1 This practice and associated standards involve handling of hot asphalt binder, aggregates, and hot mix asphalt mixtures. It also includes the use of chemical additives. Use standard safety precautions, equipment, and clothing when handling materials and operating machinery.

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7. BINDER BLEND PREPARATION

7.1 Select the base binder content, RAP and/or RAS binder content, and recycling agent dose. Refer to section 9.1 to determine recycling agent dose.

7.2 Prepare the binder blend following the steps below:

7.2.1 Extract RAP and/or RAS binders in accordance with AASHTO T 164 (test method A: centrifuge extraction), and recover the binders in accordance with ASTM D5404 (using the rotary evaporator).

Note 1—While using the rotary evaporator following ASTM D5404 is recommended for the binder recovery process, other AASHTO and ASTM standards can also be followed.

7.2.2 Preheat the base binder at elevated temperatures for about 15 minutes until the binder is adequately fluid. Preheat the RAP/RAS binders at elevated temperatures (160 to 200°C) until the binder is adequately fluid.

Note 2—Considering the high stiffness and viscosity of the recycled binders, particularly RAS binders, the extracted RAP/RAS binders should be preheated and the blending process should be performed at elevated temperatures (up to 200°C) where the binder is adequately fluid. If the RAP and/or RAS binders are not adequately fluid, binder clusters will be formed preventing a homogenous binder blend.

7.2.3 Add the recycling agent to the base binder, if used, and hand-stir using a spatula for 30 seconds.

7.2.4 Heat the blend in the oven for 1 minute, and then add the RAS binder to the binder blend, if used, and hand-stir using a spatula for 30 seconds.

7.2.5 Heat the blend in the oven for 1 minute, and then add the RAP binder to the binder blend, if used, and hand-stir using a spatula for 30 seconds.

7.2.6 Heat the blend in the oven for 1 minute, and then hand-stir the blend using a spatula for 30 seconds. Repeat this step two times to ensure the final blend is homogenous.

7.2.7 Perform RTFO aging for the binder blends directly after preparing the blends to avoid additional re-heating. Additional heating may introduce further aging.

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8. ASPHALT MIXTURE SPECIMEN PREPARATION

8.1 Select the base binder content, RAP and/or RAS content, recycling agent dose, and aggregate gradation. Follow the Superpave mix design procedure to determine binder content and aggregate gradation. Refer to section 9.1 to determine recycling agent dose, and refer to section 9.2 for the recycling agent incorporation method.

8.2 Prepare the asphalt mixture specimens following the steps below:

8.2.1 Preheat the virgin aggregate overnight at the specified mixing temperature.

8.2.2 Combine the RAP and/or RAS with the preheated virgin aggregate two hours prior to mixing, and place in the oven at the specified mixing temperature.

8.2.3 Preheat the base binder two hours prior to mixing at the required mixing temperature.

8.2.4 Add the recycling agent to the base binder, and blend well using a mixing drill, 10 minutes prior to mixing with the virgin aggregate and the RAP and/or RAS.

8.2.5 Mix the blend of base binder and recycling agent with the virgin aggregate and the RAP and/or RAS using mechanical mixer for about 1 minute. Ensure that the aggregate is thoroughly coated.

8.2.6 Empty the loose asphalt mixture in a flat shallow pan, and place the pan in the oven for 2 hours ± 5 minutes at the specified compaction temperature. This short-term oven aging (STOA) will simulate the conditioning that the mixtures experience during production and placement.

8.2.7 Follow AASHTO T 209 at the end of STOA period if the mixture is to be used to determine the maximum theoretical specific gravity. Otherwise, proceed with compaction.

8.2.8 Place the compacted specimens in a flat table to cool down for at least two hours at room temperature. Then, place the specimens in a storage room at low temperature (usually around 10°C) if the specimen is to be tested later. Otherwise, proceed with long-term oven aging (LTOA).

8.2.9 Place the compacted specimens in the oven for 5 days at 85°C in accordance with AASHTO R 30, or the proposed AASHTO TP Standard Method for Long-Term Conditioning of Hot Mix Asphalt (HMA) for Performance Testing.

Note 3—When preparing specimens with a height higher than 3 inches, extra caution should be followed during LTOA. To avoid any changes in the specimen dimensions and ensure that the target air void content remains constant, the compacted specimens can be covered with heat resistant PVC pipes or wrapped in metal wire mesh secured with clamps to avoid geometry distortion and preserve their integrity.

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9. RECYCLING AGENT DOSE SELECTION AND INCORPORATION METHODS

9.1 The recycling agent dose to restore the continuous PGH of the recycled binder blend to match PGH of the target climate (PGH_{Target}) yields the best performance for binder blends and corresponding hot mix asphalt mixtures, and yields binder blends that meet the PGL requirements of the target climate. The recycling agent dose selection method based on DSR testing of unaged material can be summarized in the following three steps:

9.1.1 Determine PGH of the base binder and RAP/RAS binders per AASHTO M 320.

9.1.2 Select the base binder, RBR, and RAP/RAS combination, and calculate PGH of the recycled binder blend using Equation 1:

$$PGH_{Blend} = (RAP_{BR} \times PGH_{RAP}) + (RAS_{BR} \times PGH_{RAS}) + (B_{BR} \times PGH_{Base}) \qquad (1)$$

where:

PGH_{Blend}	=	continuous PGH of the recycled binder blend (°C);
RAP_{BR}	=	RAP binder ratio;
PGH_{RAP}	=	continuous PGH of the RAP binder (°C);
RAS_{BR}	=	RAS binder ratio;
PGH_{RAS}	=	continuous PGH of the RAS binder (°C);
B_{BR}	=	base binder ratio = 1 – RBR; and
PGH_{Base}	=	continuous PGH of the base binder (°C).

Note 1—While accuracy in PGH may be reduced when using Equation 1, it enables consideration of multiple factors with minimal testing. It is recommended to continue to measure PGH of the recycled binder blend, if possible, for design and quality control documentation.

9.1.3 Estimate recycling agent dose using Equation 2:

$$\text{Recycling Agent (\%)} = (PGH_{Blend} - PGH_{Target}) / \text{Slope Rate} \qquad (2)$$

where:

PGH_{Blend}	=	continuous PGH of the recycled binder blend (°C) calculated from Equation 1; and
PGH_{Target}	=	continuous PGH of target climate.

Note 2— For tall oils (T), vegetable oils (V), or reacted bio-based oils (B); a recommended slope rate or rate of reduction in PGH of 1.82 can be utilized based on the materials evaluated in NCHRP Project 9-58. For aromatic extracts (A), a lower slope rate of 1.38 is recommended. Blending charts of recycling agent dose (0, 2, 5, and 10 percent) versus PGH can also be utilized to determine slope rate.

9.2 Based on recycling agent dose and recycled material type, add the recycling agent to the hot mix asphalt mixture following one of these guidelines:

9.2.1 For hot mix asphalt mixtures with only RAP and for all binder blends, the recycling agent is added as 100% replacement for the base binder.

9.2.2 For hot mix asphalt mixtures with RAP and RAS and recycling agent doses greater than 5.0%, the recycling agent is added as 100% addition with a mandatory requirement to ensure adequate mixture rutting resistance.

Note 3—These guidelines are aimed to preclude coatability issues (partially coated aggregate with base binder) that may result from replacing the base binder by the full amount of recycling agent, thus reducing the base binder content, particularly in hot mix asphalt mixtures with high recycling agent doses. These coatability issues are more prevalent in mixtures with RAS than in those with only RAP.

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10. COMPONENT MATERIALS SELECTION AND PROPORTIONING GUIDELINES

10.1 Component materials selection and proportioning guidelines are proposed in Table 1. These guidelines are provided as a system, with requirements for all applicable thresholds where data are available for a specific combination of materials in a high RBR mixture with a recycling agent.

Table 1—Component Materials Selection and Proportioning Guidelines.

Test	**Parameter**	**Component Material**			
		Base Binder	**RAP**	**RAS**	**Recycling Agent**
High-Temperature, Short-Term Aging[a]					
DSR	PGH	≤ 64°C	≤ 100°C	≤ 150°C	—
Low-Temperature, Short- and Long-Term Aging[b]					
BBR	ΔT_c	≥ −3.5°C	≥ −7.5°C	—	—
Proportioning					
RBR		—	≤ 0.5 RBR (RAP_{BR}+RAS_{BR})	≤ 0.15 RAS_{BR}	—
Dose		—	—	—	≤ 8–10%[c]

[a] Original binder and rolling thin film oven (RTFO) aged by AASHTO T 240.
[b] 20-hour PAV aging @ 100°C by AASHTO R 28.
[c] Percent of total binder in the blend/mixture.

11. BINDER BLEND RHEOLOGICAL EVALUATION TOOLS

11.1 Table 2 provides binder blend evaluation tools for use with high RBRs and recycling agents. These tools are provided as a system, with requirements recommended for at least one high-temperature and one intermediate- or low-temperature test where data are available for a specific combination of materials in a high RBR binder blend with a recycling agent.

Table 2—Binder Blend Evaluation Tools for Use with High RBRs and Recycling Agents.

Test	Parameter	Suggested Performance Threshold
High-Temperature, Original and Short-Term Aging		
DSR	PGH	Target Climate
Intermediate-Temperature, Track with Aging		
DSR	G-R	$\leq$ 180 kPa after 20-hour PAV $\leq$ 600 kPa after 40-hour PAV
DSR	$T_{\delta=45°}$	$\leq$ 32°C after 20-hour PAV $\leq$ 45°C after 40-hour PAV
Low-Temperature, Short- and Long-Term Aging		
BBR	ΔT_c	$\geq$ −5.0 after 20-hour PAV

12. MIXTURE PERFORMANCE EVALUATION TOOLS

12.1 Table 3 provides comprehensive mixture evaluation tools for use with high RBRs and recycling agents that balance mixture cracking resistance at both intermediate and low temperatures and rutting resistance at high temperatures. Evaluation of hot mix asphalt mixtures is imperative because these mixture properties control performance and allow for consideration of incomplete blending between base and recycled binders and recycling agent. These tools are provided as a system, with requirements recommended for at least one high-temperature and one intermediate- or low-temperature test where data are available for a specific materials combination in a high RBR mixture with a recycling agent.

Table 3—Mixture Evaluation Tools for Use with High RBRs and Recycling Agents.

Test	Parameter	Suggested Performance Threshold
		High-Temperature, Short-Term Aging
HWTT or APA	$N_{12.5}$	$\geq$ 5,000 for PG 58-XX $\geq$ 7,500 for PG 64-XX in cold climate $\geq$ 10,000 for PG 64-XX in warm climate $\geq$ 15,000 for PG 70-XX
		Intermediate-Temperature, Track with Aging
|E*|	$G\text{-}R_m$	$\leq$ 8,000 MPa after STOA $\leq$ 19,000 MPa after LTOA
		Intermediate-Temperature, Short-Term Aging
SCB	FI	$\geq$ 7 after STOA
		Low-Temperature, Short- and Long-Term Aging
BBR_m	S_m and m-$value_m$	$\leq$ Romero (2016) threshold on m-$value_m$ vs. S_m after STOA
UTSST	CRI_{ENV}	$\geq$ 17 after LTOA

STOA = short-term oven aging; LTOA = long-term oven aging; UTSST = uniaxial thermal stress and strain test.

13. RAP BINDER AVAILABILITY FACTOR

13.1 The amount of RAP binder in the mixture is typically represented as RAP_{BR}. However, the quantity of effective or available RAP binder in the mixture is usually unknown and less than 100%, which may yield a dry mixture with a high air void content due to less total effective binder content, potentially leading to premature distress.

13.2 The term effective or available RAP binder refers to the binder that is released from the RAP, becomes fluid, and blends with the base binder under typical mixing temperatures.

13.3 RAP binder availability factor (BAF), expressed as a decimal, can be used to adjust the base binder content in hot mix asphalt mixtures with RAP to ensure that the mix design optimum, and effective, binder content is achieved (see Note 4).

13.4 Based on the PGH of the RAP binder, the RAP BAF can be estimated using Equation 3 and Equation 4 for mixing temperatures of 140°C (284°F) and 150°C (302°F), respectively:

$$\text{RAP BAF} = -0.014 \times PGH_{RAP} + 1.898 \quad (3)$$

$$RAP\ BAF = -0.010 \times PGH_{RAP} + 1.771 \quad (4)$$

where:

PGH_{RAP} = continuous PGH of the RAP binder (°C).

Note 4—This value is suggested for use in reducing the recycled binder from the RAP to the RBR in a mixture to ensure that sufficient base binder is included during mix design.

Note 5—It is expected that adding a recycling agent in RAP mixtures would increase the RAP BAF only at low mixing temperatures. Increasing mixing temperature has an effect equivalent to adding a recycling agent.

14. REPORT

14.1 For each mix design, report the following:

14.1.1 Base binder: PG and ΔT_c

14.1.2 RAP: PGH and ΔT_c

14.1.3 RAS: PGH

14.1.4 RBR, RAP_{BR}, RAS_{BR}

14.1.5 Recycling agent type and dose

14.1.6 Selected binder blend test results (Table 2)

14.1.7 Selected mixture test results (Table 3)

15. KEYWORDS

15.1 Asphalt mixture, reclaimed asphalt pavement, recycled asphalt shingles, recycling agent, rheological properties, mixture performance

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