Standard Specification for

Superpave Volumetric Mix Design

AASHTO Designation: M 323-13

1. SCOPE

1.1. This specification for Superpave volumetric mix design uses aggregate and mixture properties to produce job-mix formulas for asphalt mixtures.

1.2. This standard specifies minimum quality requirements for binder, aggregate, and asphalt mixtures for Superpave volumetric mix designs.

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

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 320, Performance-Graded Asphalt Binder
- R 28, Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
- R 35, Superpave Volumetric Design for Asphalt Mixtures
- R 59, Recovery of Asphalt Binder from Solution by Abson Method
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 164, Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)
- T 176, Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
- T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)
- T 283, Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage
- T 304, Uncompacted Void Content of Fine Aggregate
- T 308, Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method
- T 312, Preparing and Determining the Density of Asphalt Mixture Specimens by Means of the Superpave Gyratory Compactor
- T 313, Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)
- T 315, Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)
- T 319, Quantitative Extraction and Recovery of Asphalt Binder from Asphalt Mixtures
- T 335, Determining the Percentage of Fracture in Coarse Aggregate

2.2. *ASTM Standards*:

- D4791, Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate

2.3. *Asphalt Institute Publication*:

- MS-2, *Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types*

2.4. *National Asphalt Pavement Association Publication*:

- IS 128, HMA Pavement Mix Type Selection Guide

2.5. *Other References*:

- *LTPP Seasonal Asphalt Concrete Pavement Temperature Models*. LTPPBind 3.1, http://ltpp-products.com/OtherProducts.asp
- *NCHRP Report 452: Recommended Use of Reclaimed Asphalt Pavement in the Superpave Mix Design Method: Technician's Manual*. National Cooperative Highway Research Program Project D9-12, Transportation Research Board, Washington, DC, 2001.

3. TERMINOLOGY

3.1. *design ESALs*—design equivalent (80-kN) single-axle loads.

3.1.1. *discussion*—design ESALs are the anticipated project traffic level expected on the design lane over a 20-year period. For pavements designed for more or less than 20 years, determine the design ESALs for 20 years when using this standard.

3.2. *air voids* (V_a)—the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture (Note 1).

Note 1—Term defined in Asphalt Institute Manual MS-2, *Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types*.

3.3. *voids in the mineral aggregate (VMA)*—the volume of the intergranular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective binder content, expressed as a percent of the total volume of the specimen (Note 1).

3.4. *voids filled with asphalt (VFA)*—the percentage of the VMA filled with binder (the effective binder volume divided by the VMA).

3.5. *dust-to-binder ratio* ($P_{0.075}/P_{be}$)—by mass, the ratio between the percent of aggregate passing the 75-µm (No. 200) sieve ($P_{0.075}$) and the effective binder content (P_{be}).

3.6. *nominal maximum aggregate size*—one size larger than the first sieve that retains more than 10 percent aggregate (Note 2).

3.7. *maximum aggregate size*—one size larger than the nominal maximum aggregate size (Note 2).

Note 2—The definitions given in Sections 3.7 and 3.8 apply to Superpave mixes only and differ from the definitions published in other AASHTO standards.

3.8. *reclaimed asphalt pavement (RAP)*—removed and/or processed pavement materials containing asphalt binder and aggregate.

3.9. *primary control sieve (PCS)*—the sieve defining the break point between fine- and coarse-graded mixtures for each nominal maximum aggregate size.

3.10. *reagent-grade solvent*—a solvent meeting the level of chemical purity as to conform to the specifications for "reagent grade" as established by the *Committee on Analytical Reagents of the American Chemical Society* and used to extract the asphalt binder from the mixture.

4. SIGNIFICANCE AND USE

4.1. This standard may be used to select and evaluate materials for Superpave volumetric mix designs.

5. BINDER REQUIREMENTS

5.1. The binder shall be a performance-graded (PG) binder, meeting the requirements of M 320, which is appropriate for the climate and traffic-loading conditions at the site of the paving project or as specified by the contract documents.

5.1.1. Determine the mean and the standard deviation of the yearly, 7-day-average, maximum pavement temperature, measured 20 mm below the pavement surface, and the mean and the standard deviation of the yearly, 1-day-minimum pavement temperature, measured at the pavement surface, at the site of the paving project. These temperatures can be determined by use of the LTPPBind 3.1 software or can be supplied by the specifying agency. If the LTPPBind software is used, the LTPP high- and low-temperature models should be selected in the software when determining the binder grade. Often, actual site data are not available, and representative data from the nearest weather station will have to be used.

5.1.2. Select the design reliability for the high- and low-temperature performance desired. The design reliability required is established by agency policy.

Note 3—The selection of design reliability may be influenced by the initial cost of the materials and the subsequent maintenance costs.

5.1.3. Using the pavement temperature data determined, select the minimum required PG binder that satisfies the required design reliability.

5.2. If traffic speed or the design ESALs warrant, increase the high-temperature grade by the number of grade equivalents indicated in Table 1 to account for the anticipated traffic conditions at the project site.

Table 1—Binder Selection on the Basis of Traffic Speed and Traffic Level

	Adjustment to the High-Temperature Grade of the Binder[a]		
	Traffic Load Rate		
Design ESALs[b] (Million)	Standard[c]	Slow[d]	Standing[e]
<0.3	—	—	—[f]
0.3 to <3	—	1	2
3 to <10	—	1	2
10 to <30	—[f]	1	2
≥30	1	1	2

[a] Increase the high-temperature grade by the number of grade equivalents indicated (one grade is equivalent to 6°C). Use the low-temperature grade as determined in Section 5.

[b] The anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.

[c] *Standard traffic*—where the average traffic speed is greater than 70 km/h.

[d] *Slow traffic*—where the average traffic speed ranges from 20 to 70 km/h.

[e] *Standing traffic*—where the average traffic speed is less than 20 km/h.

[f] Consideration should be given to increasing the high-temperature grade by one grade equivalent.

Note 4—Practically, PG binders stiffer than PG 82-xx should be avoided. In cases where the required adjustment to the high-temperature binder grade would result in a grade higher than a PG 82, consideration should be given to specifying a PG 82-xx and increasing the design ESALs by one level (e.g., 10 to <30 million increased to ≥30 million).

5.3. If RAP is to be used in the mixture, it may be specified according to percent dry weight (mass) of the mixture or percent binder replacement. Binder replacement is reclaimed asphalt binder from RAP that replaces virgin binder in asphalt mixtures.

5.3.1. *Percent dry weight (mass) of mixture*—If the agency elects to use RAP adjustments by percent dry weight (mass) of the mixture, the binder grade selected in Sections 5.1.3 and 5.2 needs to be adjusted according to Table 2 to account for the amount and stiffness of the RAP binder. Procedures for developing a blending chart are included in Appendix X1.

Note 5—Research conducted as part of NCHRP Project 9-12 indicated that the high stiffness RAP (PG 88-4 after recovery) used in the study had a greater effect on the low-temperature properties of the blended asphalt binder than the medium and low stiffness RAP (PG 82-16 and PG 82-22, respectively). This data suggests that the limiting RAP values in Table 2 may be modified depending on the low-temperature stiffness of the recovered RAP binder. Refer to NCHRP Report 452 for more details.

Table 2—Binder Selection Guidelines for Reclaimed Asphalt Pavement (RAP) Mixtures

Recommended Virgin Asphalt Binder Grade	RAP Percentage
No change in binder selection	<15
Select virgin binder one grade softer than normal (e.g., select a PG 58-28 if a PG 64-22 would normally be used)	15 to 25
Follow recommendations from blending charts	>25

5.3.2. *Percent binder replacement*—If the agency elects to use the percent binder replacement method, percent binder replacement is determined by the ratio of reclaimed binder to the total binder in the mixture. Geographical or project-by-project evaluations need to be completed to determine the maximum RAP amounts allowed or the minimum percentage of virgin binder.

Note 6—If recycled binder properties are not available, efforts should be undertaken to characterize typical stockpiled materials. RAP samples should be taken from typical stockpiles in various geographical locations within the state and periodically evaluated to determine the effect of various percentages of RAP binder on typical virgin PG binders. Details on the RAP evaluation process are contained in Appendix X2.

6. COMBINED AGGREGATE REQUIREMENTS

6.1. *Size Requirements:*

6.1.1. *Nominal Maximum Size*—The combined aggregate shall have a nominal maximum aggregate size of 4.75 to 19.0 mm for HMA surface courses and no larger than 37.5 mm for HMA subsurface courses.

Note 7—Additional guidance on selection of the appropriate nominal maximum size mixture can be found in the National Asphalt Pavement Association's IS 128.

6.1.2. *Gradation Control Points*—The combined aggregate shall conform to the gradation requirements specified in Table 3 when tested according to T 11 and T 27.

Table 3—Aggregate Gradation Control Points

Sieve Size, mm	Nominal Maximum Aggregate Size—Control Points (% Passing)											
	37.5 mm		25.0 mm		19.0 mm		12.5 mm		9.5 mm		4.75 mm	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
50.0	100	—	—	—	—	—	—	—	—	—	—	—
37.5	90	100	100	—	—	—	—	—	—	—	—	—
25.0	—	90	90	100	100	—	—	—	—	—	—	—
19.0	—	—	—	90	90	100	100	—	—	—	—	—
12.5	—	—	—	—	—	90	90	100	100	—	100	—
9.5	—	—	—	—	—	—	—	90	90	100	95	100
4.75	—	—	—	—	—	—	—	—	—	90	90	100
2.36	15	41	19	45	23	49	28	58	32	67	—	—
1.18	—	—	—	—	—	—	—	—	—	—	30	55
0.075	0	6	1	7	2	8	2	10	2	10	6	13

6.1.3. *Gradation Classification*—The combined aggregate gradation shall be classified as coarse-graded when it passes below the Primary Control Sieve (PCS) control point as defined in Table 4 (also see Figure 1). All other gradations shall be classified as fine-graded.

Table 4—Gradation Classification

PCS Control Point for Mixture Nominal Maximum Aggregate Size (% Passing)					
Nominal maximum aggregate size	37.5 mm	25.0 mm	19.0 mm	12.5 mm	9.5 mm
Primary control sieve	9.5 mm	4.75 mm	4.75 mm	2.36 mm	2.36 mm
PCS control point, % passing	47	40	47	39	47

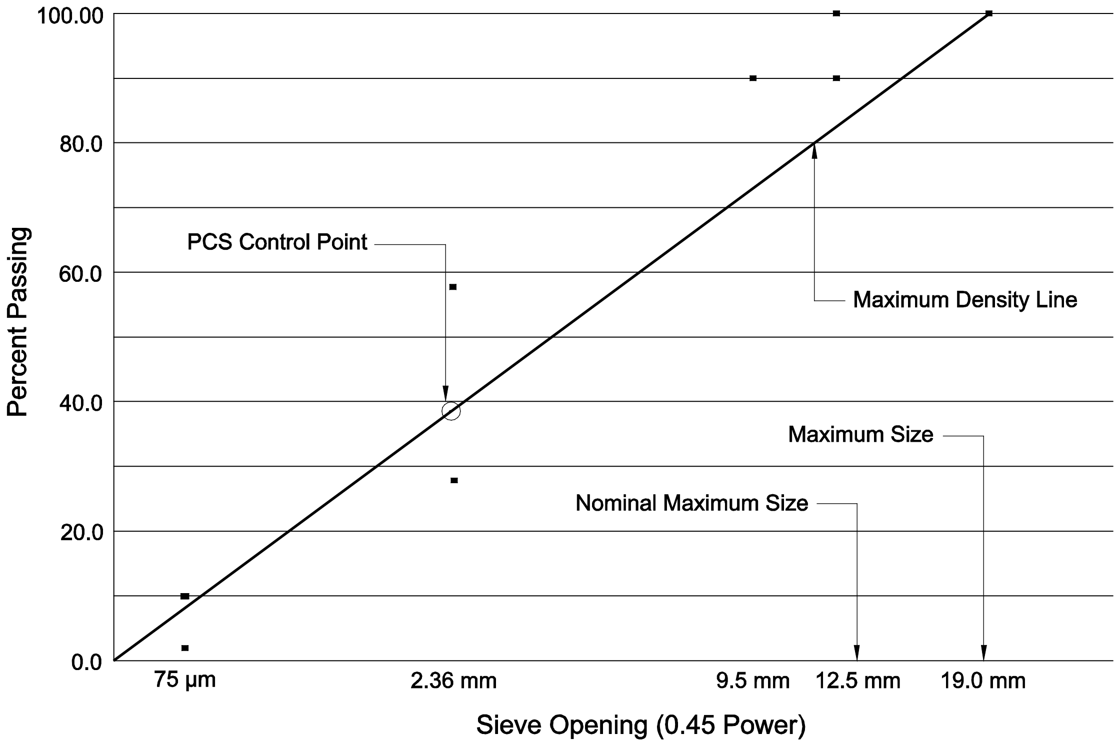

Figure 1—Superpave Gradation Control Points for a 12.5-mm Nominal Maximum Size Aggregate Gradation

6.2. *Coarse Aggregate Angularity Requirements*—The aggregate shall meet the percentage of fractured faces requirements, specified in Table 5, measured according to T 335.

6.3. *Fine Aggregate Angularity Requirements*—The aggregate shall meet the uncompacted void content of fine aggregate requirements, specified in Table 5, measured according to T 304, Method A.

6.4. *Sand Equivalent Requirements*—The aggregate shall meet the sand equivalent (clay content) requirements, specified in Table 5, measured according to T 176.

6.5. *Flat-and-Elongated Requirements*—The aggregate shall meet the flat-and-elongated requirements, specified in Table 5, measured according to ASTM D4791, with the exception that the material passing the 9.5-mm sieve and retained on the 4.75-mm sieve shall be included. The aggregate shall be measured using the ratio of 5:1, comparing the length (longest dimension) to the thickness (smallest dimension) of the aggregate particles.

6.6. When RAP is used in the mixture, the RAP aggregate shall be extracted from the RAP using a solvent extraction (T 164) or ignition oven (T 308) as specified by the agency. The RAP aggregate shall be included in determinations of gradation, coarse aggregate angularity, fine aggregate angularity, and flat-and-elongated requirements. The sand equivalent requirements shall be waived for the RAP aggregate but shall apply to the remainder of the aggregate blend.

Table 5—Superpave Aggregate Consensus Property Requirements

Design ESALs[a] (Million)	Fractured Faces, Coarse Aggregate,[c] % Minimum		Uncompacted Void Content of Fine Aggregate, % Minimum		Sand Equivalent, % Minimum	Flat and Elongated,[c] % Maximum
	Depth from Surface		Depth from Surface			
	≤100 mm	>100 mm	≤100 mm	>100 mm		
<0.3	55/—	—/—	—[d]	—	40	—
0.3 to <3	75/—	50/—	40[e]	40	40	10
3 to <10	85/80[b]	60/—	45	40	45	10
10 to <30	95/90	80/75	45	40	45	10
≥30	100/100	100/100	45	45	50	10

[a] The anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.

[b] 85/80 denotes that 85 percent of the coarse aggregate has one fractured face and 80 percent has two or more fractured faces.

[c] This criterion does not apply to 4.75-mm nominal maximum size mixtures.

[d] For 4.75-mm nominal maximum size mixtures designed for traffic levels below 0.3 million ESALs, the minimum Uncompacted Void Content is 40.

[e] For 4.75-mm nominal maximum size mixtures designed for traffic levels equal to or above 0.3 million ESALs, the minimum Uncompacted Void Content is 45.

Note 8—If less than 25 percent of a construction lift is within 100 mm of the surface, the lift may be considered to be below 100 mm for mixture design purposes.

7. HMA DESIGN REQUIREMENTS

7.1. The binder and aggregate in the HMA shall conform to the requirements of Sections 5 and 6.

7.2. The HMA design, when compacted in accordance with T 312, shall meet the relative density, VMA, VFA, and dust-to-binder ratio requirements specified in Table 6. The initial, design, and maximum number of gyrations are specified in R 35.

Table 6—Superpave HMA Design Requirements

Design ESALs,[a] million	Required Relative Density, Percent of Theoretical Maximum Specific Gravity			Voids in the Mineral Aggregate (VMA), % Minimum						Voids Filled with Asphalt (VFA) Range,[b] %	Dust-to-Binder Ratio Range[c]
				Nominal Maximum Aggregate Size, mm							
	N_{initial}	N_{design}	N_{max}	37.5	25.0	19.0	12.5	9.5	4.75		
<0.3	≤91.5	96.0	≤98.0	11.0	12.0	13.0	14.0	15.0	16.0	70–80[d,e]	0.6–1.2
0.3 to <3	≤90.5	96.0	≤98.0	11.0	12.0	13.0	14.0	15.0	16.0	65–78[f]	0.6–1.2
3 to <10	≤89.0	96.0	≤98.0	11.0	12.0	13.0	14.0	15.0	16.0	65–75[e,f,g]	0.6–1.2
10 to <30	≤89.0	96.0	≤98.0	11.0	12.0	13.0	14.0	15.0	16.0	65–75[e,f,g]	0.6–1.2
≥30	≤89.0	96.0	≤98.0	11.0	12.0	13.0	14.0	15.0	16.0	65–75[g]	0.6–1.2

[a] Design ESALs are the anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.

[b] For 37.5-mm nominal maximum size mixtures, the specified lower limit of the VFA range shall be 64 percent for all design traffic levels.

[c] For 4.75-mm nominal maximum size mixtures, the dust-to-binder ratio shall be 1.0 to 2.0, for design traffic levels <3 million ESALs, and 1.5 to 2.0 for design traffic levels ≥3 million ESALs.

[d] For 4.75-mm nominal maximum size mixtures, the relative density (as a percent of the theoretical maximum specific gravity) shall be within the range of 94.0 to 96.0 percent.

[e] For design traffic levels <0.3 million ESALs, and for 25.0-mm nominal maximum size mixtures, the specified lower limit of the VFA range shall be 67 percent, and for 4.75-mm nominal maximum size mixtures, the specified VFA range shall be 67 to 79 percent.

[f] For design traffic levels >0.3 million ESALs, and for 4.75-mm nominal maximum size mixtures, the specified VFA range shall be 66 to 77 percent.

[g] For design traffic levels ≥3 million ESALs, and for 9.5-mm nominal maximum size mixtures, the specified VFA range shall be 73 to 76 percent.

Note 9—If the aggregate gradation passes beneath the PCS Control Point specified in Table 4, the dust-to-binder ratio range may be increased from 0.6–1.2 to 0.8–1.6 at the agency's discretion.

Note 10—Mixtures with VMA exceeding the minimum value by more than 2 percent may be prone to flushing and rutting. Unless satisfactory experience with high VMA mixtures is available, mixtures with VMA greater than 2 percent above the minimum should be avoided.

7.3. The HMA design, when compacted according to T 312 at 7.0 ± 0.5 percent air voids and tested in accordance with T 283, shall have a minimum tensile strength ratio of 0.80.

APPENDIXES

(Nonmandatory Information)

X1. PROCEDURES FOR DEVELOPING A BLENDING CHART

X1.1. Blending of RAP binders can be accomplished by knowing the desired final grade (critical temperature) of the blended binder, the physical properties (and critical temperatures) of the recovered RAP binder, and either the physical properties (and critical temperatures) of the virgin asphalt binder or the desired percentage of RAP in the mixture.

X1.2. *Determine the physical properties and critical temperatures of the RAP binder*:

X1.2.1. Recover the RAP binder using T 319 (Note X1) with an appropriate solvent. At least 50 g of recovered RAP binder are needed for testing. Perform binder classification testing using the tests in M 320. Rotational viscosity, flash point, and mass loss tests are not required.

Note X1—While T 319 is the preferred method, at the discretion of the agency, R 59 may be used. Research conducted under NCHRP 9-12 indicated that R 59 might affect recovered binder properties.

X1.2.2. Perform original dynamic shear rheometer (DSR) testing on the recovered RAP binder to determine the critical high temperature, $T_c(High)$, based on original DSR values where $G^*/\sin\delta = 1.00$ kPa. Calculate the critical high temperature as follows:

X1.2.2.1. Determine the slope of the stiffness–temperature curve as follows:

$$a = \Delta\log(G^*/\sin\delta)/\Delta T \qquad (X1.1)$$

X1.2.2.2. Determine T_c (*High*) to the nearest 0.1°C using the following equation:

$$T_c\,(High) = \left(\frac{\log(1.00) - \log(G_1)}{a}\right) + T_1 \qquad (X1.2)$$

where:

G_1 = the $G^*/\sin\delta$ value at a specific temperature T_1; and

a = the slope as described in Equation X1.1.

Note X2—Although any temperature (T_1) and the corresponding stiffness (G_1) can be selected, it is advisable to use the $G^*/\sin\delta$ value closest to the criterion (1.00 kPa) to minimize extrapolation errors.

X1.2.3. Perform rolling thin-film oven (RTFO) aging on the remaining binder.

X1.2.4. Perform RTFO DSR testing on the RTFO-aged recovered binder to determine the critical high temperature (based on RTFO DSR). Calculate the critical high temperature (RTFO DSR).

X1.2.4.1. Determine the slope of the Stiffness-Temperature curve as follows:

$$a = \Delta \log(G^*/\sin\delta)/\Delta T \qquad (X1.3)$$

X1.2.4.2. Determine $T_c(High)$ based on RTFO DSR, to the nearest 0.1°C using the following equation:

$$T_c(High) = \left(\frac{\log(2.20) - \log(G_1)}{a}\right) + T_1 \qquad (X1.4)$$

where:

G_1 = the G*/sin δ value at a specific temperature T_1; and

a = the slope as described in Equation X1.3.

Note X3—Although any temperature (T_1) and the corresponding stiffness (G_1) can be selected, it is advisable to use the G*/sin δ value closest to the criterion (2.20 kPa) to minimize extrapolation errors.

X1.2.5. Determine the critical high temperature of the recovered RAP binder as the lowest of the original DSR and RTFO DSR critical temperatures. Determine the high-temperature performance grade (PG) of the recovered RAP binder based on this single critical high temperature.

X1.2.6. Perform intermediate temperature DSR testing on the RTFO-aged recovered RAP binder to determine the critical intermediate temperature T_c (*Int*), as if the RAP binder were pressure-aging-vessel (PAV) aged.

X1.2.6.1. Determine the slope of the stiffness–temperature curve as follows:

$$a = \Delta \log(G^*/\sin\delta)/\Delta T \qquad (X1.5)$$

X1.2.6.2. Determine T_c (*Int*) to the nearest 0.1°C using the following equation:

$$T_c(Int) = \left(\frac{\log(5000) - \log(G_1)}{a}\right) + T_1 \qquad (X1.6)$$

where:

G_1 = the G*/sin δ value at a specific temperature T_1, and

a = the slope as described in Equation X1.5.

Note X4—Although any temperature (T_1) and the corresponding stiffness (G_1) can be selected, it is advisable to use the G*/sin δ value closest to the criterion (5000 kPa) to minimize extrapolation errors.

X1.2.7. Perform BBR testing on the RTFO-aged recovered RAP binder to determine the critical low temperature, T_c (*S*) or T_c (*m*), based on bending beam rheometer (BBR) Stiffness or *m*-value.

X1.2.7.1. Determine the slope of the stiffness–temperature curve as follows:

$$a = \Delta \log(S)/\Delta T \tag{X1.7}$$

X1.2.7.2. Determine $T_c(S)$ to the nearest 0.1°C using the following equation:

$$T_c(S) = \left(\frac{\log(300) - \log(S_1)}{a}\right) + T_1 \tag{X1.8}$$

where:

S_1 = the S-value at a specific temperature T_1; and

a = the slope as described in Equation X1.7.

Note X5—Although any temperature (T_1) and the corresponding stiffness (S_1) can be selected, it is advisable to use the S-value closest to the criterion (300 MPa) to minimize extrapolation errors.

X1.2.7.3. Determine the slope of the m-value–temperature curve as follows:

$$a = \Delta m\text{-value}/\Delta T \tag{X1.9}$$

X1.2.7.4. Determine $T_c(m)$ to the nearest 0.1°C using the following equation:

$$T_c(m) = \left(\frac{0.300 - m_1}{a}\right) + T_1 \tag{X1.10}$$

where:

m_1 = the m-value at a specific temperature T_1; and

a = the slope as described in Equation X1.9.

Note X6—Although any temperature (T_1) and the corresponding m-value (m_1) can be selected, it is advisable to use the m-value closest to the criterion (0.300) to minimize extrapolation errors.

X1.2.7.5. Select the higher of the two low critical temperatures, $T_c(S)$ or $T_c(m)$, to represent the low critical temperature for the recovered asphalt binder, $T_c(Low)$. Determine the low-temperature PG of the recovered RAP binder based on this single critical low temperature.

X1.2.8. Once the physical properties and critical temperatures of the recovered RAP binder are known, proceed with blending at a known RAP percentage or with a known virgin binder grade.

X1.3. *Blending at a known RAP percentage*:

X1.3.1. If the desired final blended binder grade, the desired percentage of RAP, and the recovered RAP binder properties are known, then the required properties of an appropriate virgin binder grade can be determined.

X1.3.1.1. Determine the critical temperatures of the virgin asphalt binder at high, intermediate, and low properties using the following equation:

$$T_{\text{virgin}} = \frac{T_{\text{blend}} - (\%\text{RAP} \times T_{\text{RAP}})}{(1 - \%\text{RAP})} \qquad (X1.11)$$

where:

T_{virgin} = critical temperature of virgin asphalt binder (high, intermediate, or low);
T_{blend} = critical temperature of blended asphalt binder (final desired) (high, intermediate, or low);
%RAP = percentage of RAP expressed as a decimal; and
T_{RAP} = critical temperature of recovered RAP binder (high, intermediate, or low).

X1.3.1.2. Using Equation X1.11 for the high, intermediate, and low critical temperatures, respectively, the properties of the virgin asphalt binder needed can be determined.

X1.4. *Blending with a known virgin binder*:

X1.4.1. If the final blended binder grade, virgin asphalt binder grade, and recovered RAP properties are known, then the allowable RAP percentage can be determined.

X1.4.1.1. Determine the allowable RAP percentage using the following equation:

$$\%\text{RAP} = \frac{T_{\text{blend}} - T_{\text{virgin}}}{T_{\text{RAP}} - T_{\text{virgin}}} \qquad (X1.12)$$

where:

T_{virgin} = critical temperature of virgin asphalt binder (high, intermediate, or low);
T_{blend} = critical temperature of blended asphalt binder (high, intermediate, or low); and
T_{RAP} = critical temperature of recovered RAP binder (high, intermediate, or low).

X1.4.1.2. Using Equation X1.12 for the high, intermediate, and low critical temperatures, respectively, the allowable RAP percentage that will satisfy all temperatures can be determined.

X2. PROCEDURES FOR EVALUATING RAP STOCKPILES

X2.1. The purpose of this appendix is to characterize properties of RAP asphalt binder within a geographical area to determine the appropriate percentages of RAP at which virgin asphalt binder properties should be changed for that geographical area.

X2.2. RAP stockpiles locations should be selected throughout the geographical area. Geographical areas should be selected with consideration to climatic zones and material sources. The number of stockpile locations may depend upon the size of the geographical area, variability of climate within the area, and the variation of factors within the area.

X2.3. Evaluation of the physical properties of the recovered RAP binder begins with the sampling and testing of the stockpiles within the geographical area. The sample should be large enough to provide a sufficient amount of recovered asphalt binder for PG grading.

X2.4. In locations where RAP containing modified binders is stockpiled separately, evaluation of the RAP asphalt binder should be performed separately from other stockpiles.

X2.5. Solvent extractions should be performed on the RAP samples to acquire recovered binder samples. Reagent-grade solvents should be used to reduce the potential of the extraction process changing the properties of the recovered binder.

X2.6. Determine the physical properties and critical failure temperatures of the RAP binders as outlined in Appendix X1.

X2.7. In some cases the high temperature grade of the recovered binder may be higher than the temperature range of the DSR equipment. For these cases, the binder should be tested at three temperatures: –3, –9, and –15°C from the high temperature limit of the equipment. Plot the log of the test temperature versus the log of the binder property to project the temperature at which the binder will meet the grade requirements. All binder grading should be performed to provide the actual continuous grades of the RAP binder.

X2.8. Determine the distribution of RAP binder grades from stockpiles within the geographical area of study. From the distribution of temperature grades, calculate the average high and low temperature grades from the RAP stockpiles. The average temperature grade plus two standard deviations will provide 96 percent reliability for the temperature grade of the RAP binders in the geographical area of study.

X2.9. Collect multiple samples of asphalt binder for each grade supplied into the geographical area of study. Determine the continuous high and low temperatures grade for each binder. The average temperature grade plus two standard deviations will provide 96 percent reliability for the temperature grade of the virgin binders in the geographical area. Use the highest or the 96 percent reliability continuous temperature grade in the blending analysis.

X2.10. Perform a blending analysis using Section X1.4 to determine the maximum allowable percent of RAP binder to be added to a virgin asphalt binder to meet the needed temperature grade according to the LTPPBind 3.1 software.

Note X7—For example, PG xx-22 may be specified; however, a RAP blend that produces a PG xx-16 may provide 98 percent reliability according to the LTPPBind 3.1 software. In most cases, reliabilities of less than 98 percent are acceptable and will result in only minor temperature differences.

X2.11. Evaluation of asphalt binder recovered from RAP stockpiles in a typical geographical area allows asphalt binder replacement from RAP based on properties of both RAP and virgin binders. This approach allows determination of maximum asphalt binder replacement limits without changing the virgin binder grade. It also establishes the maximum amount of asphalt binder replacement that can be used with a virgin binder that is one temperature grade lower. This information can be used to establish design criteria within a specific geographical area. In areas where the recovered properties vary significantly, establishing a general RAP percentage use may not be appropriate. In these cases, the analysis should be performed on a project-by-project basis. Reevaluation of the analysis of the maximum asphalt binder replacement amounts should be completed periodically to address changes in the binders for any given geographical area.