APPENDIX F: APPENDIX A, Proposed AASHTO Specification Revisions

Proposed Revisions to
Standard Specification for
Superpave Volumetric Mix Design

AASHTO Designation: MP2-00[1, 2]

1. Scope

1.1 This specification for Superpave volumetric mix design uses aggregate and mixture properties to produce a hot-mix asphalt (HMA) job-mix formula.

1.2 This standard specifies minimum quality requirements for binder, aggregate, and HMA 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 problems 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:

T11 Materials Finer Than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing
T27 Sieve Analysis of Fine and Coarse Aggregates
T176 Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
T283 Resistance of Compacted Bituminous Mixture to Moisture Induced Damage
T304 Uncompacted Void Content of Fine Aggregate
MP1 Specification for Performance Graded Asphalt Binder
PP28 Superpave Volumetric Design for HMA
TP4 Preparing and Determining the Density of Hot-Mix Asphalt Specimens by Means of the Superpave Gyratory Compactor

2.2 ASTM Standards:

D5821 Determining the Percentage of Fractured Particles in Coarse Aggregate

D4791 Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate

2.3 Other References:

"LTPP Seasonal Asphalt Concrete Pavement Temperature Models, FHWA-RD-97-103," September, 1998.

3. Terminology

3.1 HMA - Hot-Mix Asphalt

3.2 Design ESALs - Design equivalent (80kN) single-axle loads

> 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.

3.3 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 the Asphalt Institute Manual MS-2, "Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types."

3.4 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,

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[1] This standard is based on SHRP Product M001.

[2] Approved in December 1995, this provisional standard was first published in June 1996.

expressed as a percent of the total volume of the specimen (Note 1).

3.5 Voids Filled With Asphalt (VFA) - The percentage of the VMA filled with binder (the effective binder volume divided by the VMA).

3.6 Dust-to-Binder Ratio $(P_{0.075}/P_{be})$ - By mass, the ratio between the percent of aggregate passing the 0.075 mm (#200) sieve $(P_{0.075})$ and the effective binder content (P_{be}).

3.7 Nominal Maximum Aggregate Size - One size larger than the first sieve that retains more than 10 percent aggregate (Note 2).

3.8 Maximum Aggregate Size - One size larger than the nominal maximum aggregate size (Note 2).

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

3.9 Reclaimed Asphalt Pavement (RAP) - removed and/or processed pavement materials containing asphalt binder and aggregate

4. Significance and Use - 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 MP1, 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 software or 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 is 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.

5.3 If RAP is to be used in the mixture, adjust the binder grade selected in 5.1.3 and 5.2 according to Table 2 to account for the RAP binder stiffness and amount. Procedures for developing a blending chart are included in the Appendix.

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 9.5 to 19.0 mm for HMA surface course and 19.0 to 37.5 mm for HMA subsurface courses.

6.1.2 Gradation Control Points - The combined aggregate shall conform to the gradation requirements specified in Table 3~~2~~ when tested according to T11 and T27.

6.1.3 Gradation Restricted Zones - It is recommended that the selected combined aggregate gradation does not pass through the restricted zones specified in Table 4~~3~~. See Figure 1 for an example of a graph showing the gradation control points and the restricted zone.

6.2 Coarse Aggregate Angularity Requirements - The aggregate shall meet the coarse aggregate angularity requirements, specified in Table 5~~4~~, measured according to D5821.

6.3 Fine Aggregate Angularity Requirements - The aggregate shall meet the uncompacted void content of fine aggregate requirements, specified in Table 5~~4~~, measured according to T304, Method A.

6.4 Sand Equivalent Requirements - The aggregate shall meet the sand equivalent (clay content) requirements, specified in Table 54, measured according to T176.

6.5 Flat-and-Elongated Requirements - The aggregate shall meet the flat-and-elongated requirements, specified in Table 54, measured according to 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 or ignition oven 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.

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 TP4, shall meet the relative density, VMA, VFA, and dust-to-binder ratio requirements specified in Table 65. The initial, design, and maximum number of gyrations are specified in PP28.

7.3 The HMA design, when compacted according to TP4 at 7 ± 1.0 percent air voids and tested in accordance with T283 shall have a tensile strength ratio of at least 0.80.

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

Design ESALs[1] (million)	Adjustment to the High Temperature Grade of the Binder[5]		
	Traffic Load Rate		
	Standing[2]	Slow[3]	Standard[4]
< 0.3	_[6]	-	-
0.3 to < 3	2	1	-
3 to < 10	2	1	-
10 to < 30	2	1	_[6]
≥ 30	2	1	1

(1) 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.
(2) Standing Traffic - where the average traffic speed is less than 20 km/h.
(3) Slow Traffic - where the average traffic speed ranges from 20 to 70 km/h.
(4) Standard Traffic - where the average traffic speed is greater than 70 km/h.
(5) 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.
(6) 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).

Table 2 - Binder Selection Guidelines for RAP Mixtures

Recommended Virgin Asphalt Binder Grade	RAP Percentage		
	Recovered RAP Grade		
	PG xx-22 or lower	PG xx-16	PG xx-10 or higher
No change in binder selection	<20%	<15%	<10%
Select virgin binder one grade softer than normal (i.e., select a PG 58-28 if a PG 64-22 would normally be used.	20 - 30%	15 - 25%	10 - 15%
Follow recommendations from blending charts	>30%	>25%	>15%

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Table 32 - Aggregate Gradation Control Points

| Sieve Size | Nominal Maximum Aggregate Size - Control Point (Percent Passing) | | | | | | | | | |
| | 37.5 mm | | 25.0 mm | | 19.0 mm | | 12.5 mm | | 9.5 mm | |
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
50.0 mm	100	--	--	--	--	--	--	--	--	--
37.5 mm	90	100	100	--	--	--	--	--	--	--
25.0 mm	--	90	90	100	100	--	--	--	--	--
19.0 mm	--	--	--	90	90	100	100	--	--	--
12.5 mm	--	--	--	--	--	90	90	100	100	--
9.5 mm	--	--	--	--	--	--	--	90	90	100
4.75 mm	--	--	--	--	--	--	--	--	--	90
2.36 mm	15	41	19	45	23	49	28	58	32	67
0.075 mm	0	6	1	7	2	8	2	10	2	10

Table 4̶3̶ - Boundaries of Aggregate Restricted Zone

Sieve Size Within Restricted Zone	Minimum and Maximum Boundaries by Sieve Size for Nominal Maximum Aggregate Size (Minimum and Maximum Percent Passing)									
	37.5 mm		25.0 mm		19.0 mm		12.5 mm		9.5 mm	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
0.300 mm	10.0	10.0	11.4	11.4	13.7	13.7	15.5	15.5	18.7	18.7
0.600 mm	11.7	15.7	13.6	17.6	16.7	20.7	19.1	23.1	23.5	27.5
1.18 mm	15.5	21.5	18.1	24.1	22.3	28.3	25.6	31.6	31.6	37.6
2.36 mm	23.3	27.3	26.8	30.8	34.6	34.6	39.1	39.1	47.2	47.2
4.75 mm	34.7	34.7	39.5	39.5	--	--	--	--	--	--

Table 5̶4̶ - Superpave Aggregate Consensus Property Requirements

Design ESALs[1] (million)	Coarse Aggregate Angularity (Percent), minimum		Uncompacted Void Content of Fine Aggregate (Percent), minimum		Sand Equivalent (Percent), minimum	Flat and Elongated (Percent), maximum
	≤ 100 mm	> 100 mm	≤ 100 mm	> 100 mm		
< 0.3	55/-	-/-	-	-	40	-
0.3 to < 3	75/-	50/-	40	40	40	10
3 to < 10	85/80[2]	60/-	45	40	45	
10 to < 30	95/90	80/75	45	40	45	
≥ 30	100/100	100/100	45	45	50	

1   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.

2   85/80 denotes that 85 % of the coarse aggregate has one fractured face and 80 % has two or more fractured faces.

Note 5 -   If less than 25 % 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.

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Table 65 - Superpave HMA Design Requirements

Design ESALs[1] (million)	Required Relative Density (% of Theoretical Maximum Specific Gravity)			Voids in the Mineral Aggregate (Percent), minimum					Voids Filled With Asphalt Range (Percent)	Dust-to-Binder Ratio Range
	$N_{initial}$	N_{design}	N_{max}	Nominal Maximum Aggregate Size, mm						
				37.5	25.0	19.0	12.5	9.5		
< 0.3	≤ 91.5								70 - 80 [3]	
0.3 to < 3	≤ 90.5								65 - 78	
3 to < 10	≤ 89.0	96.0	≤ 98.0	11.0	12.0	13.0	14.0	15.0	65 - 75 [2]	0.6 - 1.2
10 to < 30										
≥ 30										

(1) 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.

(2) For 9.5-mm nominal maximum size mixtures, the specified VFA range shall be 73 to 76% for design traffic levels ≥ 3 million ESALs.

(3) For 25.0-mm nominal maximum size mixtures, the specified lower limit of the VFA shall be 67% for design traffic levels < 0.3 million ESALs.

(4) For 37.5-mm nominal maximum size mixtures, the specified lower limit of the VFA shall be 64% for all design traffic levels.

Note 6 - If the aggregate gradation passes beneath the boundaries of the aggregate restricted zone specified in Table 3, the dust-to-binder ratio range may be increased from 0.6 - 1.2 to 0.8 - 1.6 at the agency's discretion.
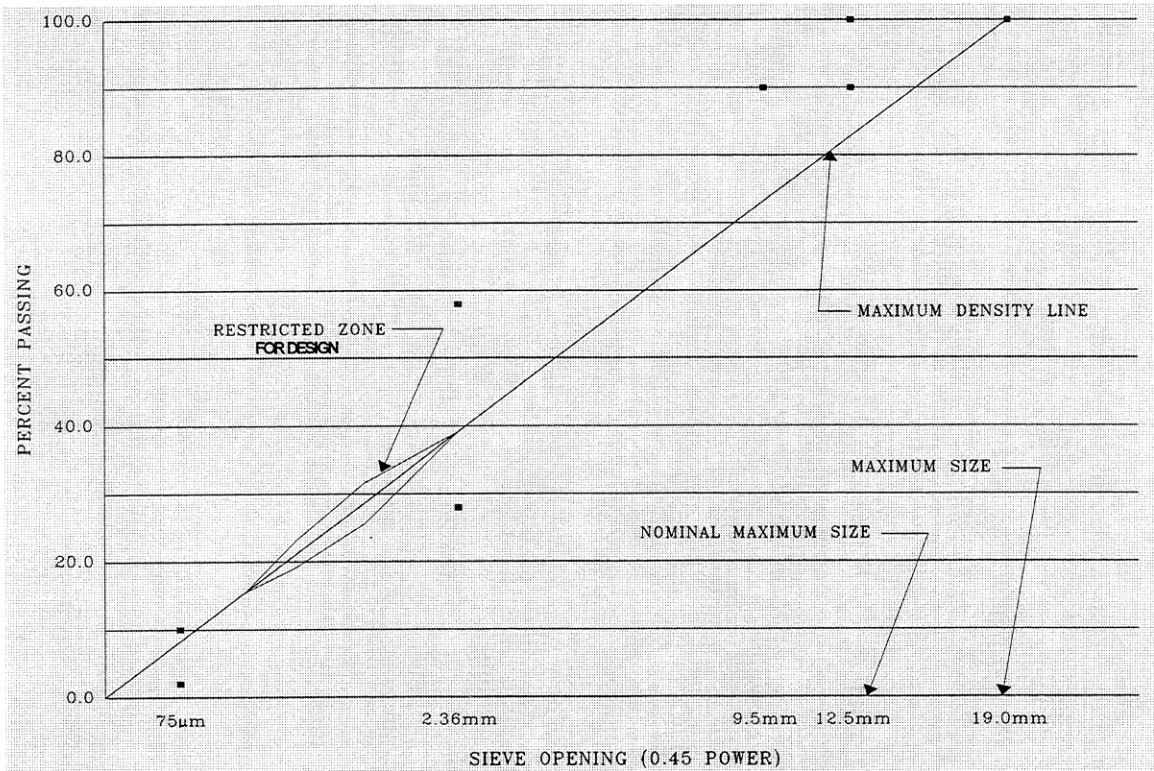
Figure 1: Superpave Gradation Control Points and Restricted Zone for a 12.5 mm Nominal Maximum Size Aggregate Gradation

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 Determine the physical properties and critical temperatures of the RAP binder.

X1.1 Recover the RAP binder using the AASHTO TP2 method (revised 6/00) with an appropriate solvent. At least 50 g of recovered RAP binder are needed for testing. Perform binder classification testing using the tests in AASHTO MP1. Rotational viscosity, flash point and mass loss tests are not required.

X1.2 Perform original 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.

X1.2.1 Determine the slope of the Stiffness-Temperature curve, a, as a $= \Delta\log(G*/\sin \delta)/\Delta T$.

X1.2.2 Determine T_c(High) to the nearest 0.1°C using the following equation:

$$T_c(High) = \left(\frac{Log(1.00) - Log(G_1)}{a} \right) + T_1$$

where,
   $G_1 =$ the $G*/\sin \delta$ value at a specific temperature T_1
   a $=$ the slope as described in X1.2..1

   Note: 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.

X1.3 Perform RTFO aging on the remaining binder.

X1.4 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) as follows:

X1.4.1 Determine the slope of the Stiffness-Temperature curve, a, as a $= \Delta\log(G*/\sin \delta)/\Delta T$.

X1.4.2 Determine T_c(High), based on RTFO DSR, to the nearest 0.1°C using the following equation:

$$T_c(High) = \left(\frac{Log(2.20) - Log(G_1)}{a} \right) + T_1$$

where,
   $G_1 =$ the $G*/\sin \delta$ value at a specific temperature T_1
   a $=$ the slope as described in X1.4.1

   Note: Although any temperature (T_{11}) and the corresponding stiffness (G_1) can be selected, it is advisable to use the $G*/\sin \delta$ value closest to the criterion (2.20 kPa) to minimize extrapolation errors.

X1.5 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 of the recovered RAP binder based on this single critical high temperature.

X1.6 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 PAV aged.

X1.6.1 Determine the slope of the Stiffness-Temperature curve, a, as a $= \Delta\log(G*\sin \delta)/\Delta T$.

X1.6.2 Determine T_c(Int) to the nearest 0.1°C using the following equation:

$$T_c(Int) = \left(\frac{Log(5000) - Log(G_1)}{a} \right) + T_1$$

where,
   $G_1 =$ the $G*\sin \delta$ value at a specific temperature T_1
   a $=$ the slope as described in X1.6.1

   Note: 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 (5000 kPa) to minimize extrapolation errors.

X1.7 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 BBR Stiffness or m-value.

X1.7.1 Determine the slope of the Stiffness-Temperature curve as $\Delta \log(S)/\Delta T$

X1.7.2 Determine $T_c(S)$ to the nearest 0.1°C using the following equation:

$$T_c(S) = \left(\frac{Log(300) - Log(S_1)}{a} \right) + T_1$$

where,

S_1 = the S-value at a specific temperature T_1
a = the slope as described in X1.7.1

Note: 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.

X1.7.3 Determine the slope of the m-value-Temperature curve as Δm-value/ΔT

X1.7.4 Determine $T_c(m)$ to the nearest 0.1°C using the following equation:

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

where,

m_1 = the m-value at a specific temperature T_1
a = the slope as described in X1.7.3

Note: 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.

X1.7.5 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 performance grade of the recovered RAP binder based on this single critical low temperature.

X1.8 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.

X2. Blending at a Known RAP Percentage

X2.1 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.

X2.1.1 Determine the critical temperatures of the virgin asphalt binder at high, intermediate and low properties as:

$$T_{Virgin} = \frac{T_{Blend} - (\%RAP \times T_{RAP})}{(1 - \%RAP)}$$

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
T_{RAP} = critical temperature of recovered RAP binder (high, intermediate or low)

Using this equation for the high, intermediate and low critical temperatures respectively, the properties of the virgin asphalt needed can be determined.

X3 Blending with a Known Virgin Binder

X3.1 If the final blended binder grade, virgin asphalt binder grade and recovered RAP properties are known, then the allowable RAP percentage can be determined.

X3.1.1 Determine the allowable RAP percentage as:

$$\%RAP = \frac{T_{Blend} - T_{Virgin}}{T_{RAP} - T_{Virgin}}$$

where:

T_{Virgin} = critical temperature of the virgin asphalt binder (high, intermediate or low)
T_{Blend} = critical temperature of the blended asphalt binder (high, intermediate or low)
T_{RAP} = critical temperature of the recovered RAP binder (high, intermediate or low)

Using this equation for the high, intermediate and low critical temperatures respectively, the allowable RAP percentage that will satisfy all temperatures can be determined.

MP2

Suggested Revisions to
**Standard Practice for Superpave
Volumetric Design for Hot-Mix Asphalt (HMA)**

AASHTO Designation: PP28-00[1, 2]

1. Scope

1.1 This standard for mix design evaluation uses aggregate and mixture properties to produce a hot-mix asphalt (HMA) job-mix formula. The mix design is based on the volumetric properties of the HMA in terms of the air voids, voids in the mineral aggregate (VMA), and voids filled with asphalt (VFA).

1.2 This standard may also be used to provide a preliminary selection of mix parameters as a starting point for mix analysis and performance prediction analyses which primarily use TP7 and TP9.

1.3 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 determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 AASHTO Standards:

T2	Sampling of Aggregates
T11	Materials Finer Than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing
T27	Sieve Analysis of Fine and Coarse Aggregates
T84	Specific Gravity and Absorption of Fine Aggregate
T85	Specific Gravity and Absorption of Coarse Aggregate
T100	Specific Gravity of Soils
T166	Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens
T209	Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures

T228	Specific Gravity of Semi-Solid Bituminous Materials
T248	Reducing Samples of Aggregate to Testing Size
T275	Bulk Specific Gravity of Compacted Bituminous Mixtures Using Paraffin-Coated Specimens
T283	Resistance of Compacted Bituminous Mixture to Moisture Induced Damage
MP1	Performance Graded Asphalt Binder
MP2	Superpave Volumetric Mix Design
PP2	Mixture Conditioning of Hot-Mix Asphalt (HMA)
TP4	Preparing and Determining the Density of Hot-Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor
TP7	Determining the Permanent Deformation and Fatigue Cracking Characteristics of Hot-Mix Asphalt (HMA) Using the Simple Shear Test (SST) Device
TP9	Determining the Creep Compliance and Strength of Hot-Mix Asphalt (HMA) Using the Indirect Tensile Test Device

3. Terminology

3.1 HMA - Hot-Mix Asphalt

3.2 Design ESALs - Design equivalent (80kN) single-axle loads

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.

3.3 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

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[1] This standard is based on SHRP Product M001.

[2] Approved in December 1995, this provisional standard was first published in June 1996.

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."

3.4 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).

3.5 Absorbed binder volume (V_{ba}) - The volume of binder absorbed into the aggregate (equal to the difference in aggregate volume when calculated with the bulk specific gravity and effective specific gravity).

3.6 Binder content (P_b) - The percent by mass of binder in the total mixture including binder and aggregate.

3.7 Effective binder volume (V_{be}) - The volume of binder which is not absorbed into the aggregate.

3.8 Voids Filled With Asphalt (VFA) - The percentage of the VMA filled with binder (the effective binder volume divided by the VMA).

3.9 Dust-to-Binder Ratio ($P_{0.075}/P_{be}$) - By mass, ratio between percent passing the 0.075 mm (# 200) sieve ($P_{0.075}$) and the effective binder content (P_{be}).

3.10 Nominal Maximum Aggregate Size - One size larger than the first sieve that retains more than 10 percent aggregate (Note 2).

3.11 Maximum Aggregate Size - One size larger than the nominal maximum aggregate size (Note 2).

> Note 2 - The definitions given in Subsections 3.10 and 3.11 apply to Superpave mixes only and differ from the definitions published in other AASHTO standards.

3.12 Reclaimed Asphalt Pavement (RAP) - removed and/or processed pavement material containing asphalt binder and aggregate.

4. Summary of the Practice

4.1 Materials Selection - Binder and aggregate and

RAP stockpiles are selected that meet the environmental and traffic requirements applicable to the paving project. The bulk specific gravity of all aggregates proposed for blending and the specific gravity of the binder are determined.

> Note 3 - If RAP is used, the bulk specific gravity of the RAP aggregate may be estimated by determining the G_{mm} of the RAP mixture and using an assumed asphalt absorption for the RAP aggregate to calculate the RAP aggregate bulk specific gravity, if the absorption can be estimated with confidence. The RAP aggregate effective specific gravity may be used in lieu of the bulk specific gravity at the discretion of the Agency. The use of the effective specific gravity may introduce an error into the combined aggregate bulk specific gravity and subsequent VMA calculations. The Agency may choose to specify adjustments to the VMA requirements to account for this error based on experience with their local aggregates.

4.2 Design Aggregate Structure - At least three trial aggregate gradations from selected aggregate stockpiles are blended. For each trial gradation, an initial trial binder content is determined, and at least two specimens are compacted in accordance with TP4. A design aggregate structure and an estimated design binder content are selected on the basis of satisfactory conformance of a trial gradation meeting the requirements given in MP2 for V_a, VMA, VFA, dust-to-binder ratio at N_{design}, and relative density at $N_{initial}$.

4.3 Design Binder Content Selection - Replicate specimens are compacted in accordance with TP4 at the estimated design binder content and at the estimated design binder content $\pm$ 0.5 percent and + 1.0 percent. The design binder content is selected on the basis of satisfactory conformance with the requirements of MP2 for V_a, VMA, VFA, and dust-to-binder ratio at N_{des}, and the relative density at N_{ini} and N_{max}.

4.4 Evaluating Moisture Susceptibility - The moisture susceptibility of the design aggregate structure is evaluated at the design binder content: the mixture is conditioned according to the mixture conditioning for the volumetric mixture design procedure in PP2, compacted to 7 ± 1.0 percent air voids in accordance with TP4, and evaluated according to T283. The design shall meet the tensile strength ratio requirement of MP2.

5. Significance and Use - The procedure described in this practice is used to produce HMA which satisfies Superpave HMA volumetric mix design requirements.

6. Preparing Aggregate Trial Blend Gradations

6.1 Select a binder in accordance with the requirements of MP2.

6.2 Determine the specific gravity of the binder according to T228.

6.3 Obtain samples of aggregates proposed to be used for the project from the aggregate stockpiles in accordance with T2.

> Note 43 - Each stockpile usually contains a given size of an aggregate fraction. Most projects employ 3 to 5 stockpiles to generate a combined gradation conforming to the job-mix formula and MP2.

6.4 Reduce the samples of aggregate fractions according to T248 to samples of the size specified in T27.

6.5 Wash and grade each aggregate sample according to T11 and T27.

6.6 Determine the bulk and apparent specific gravity for each coarse and fine aggregate fraction in accordance with T85 and T84, respectively, and determine the specific gravity of the mineral filler in accordance with T100.

6.7 Blend the aggregate fractions using Equation 1:

$$P = Aa + Bb + Cc, \text{ etc.} \qquad (1)$$

where:

P = the percentage of material passing a given sieve for the combined aggregates A, B, C, etc.;

A, B, C, etc. = the percentage of material passing a given sieve for aggregates A, B, C, etc.; and

a, b, c, etc. = the proportions of aggregates A, B, C, etc. used in the combination, and where the total = 1.00.

6.8 Prepare a minimum of three aggregate trial blends; plot the gradation of each trial blend on a

0.45-power gradation analysis chart, and confirm that each trial blend meets MP2 gradation controls (see Tables 2 and 3 of MP2). Gradation control is based on four control sieve sizes: the sieve for the maximum aggregate size, the sieve for the nominal maximum aggregate size, the 4.75 or 2.36 mm sieve, and the 0.075 mm sieve. An example of three acceptable trial blends in the form of a gradation plot is given in Figure 1.

6.9 Obtain a test specimen from each of the trial blends according to T248, and conduct the quality tests specified in Section 6 of MP2 to confirm that the aggregate in the trial blends meets the minimum quality requirements specified in MP2.

> Note 54 - The designer has an option of performing the quality tests on each stockpile instead of the trial aggregate blend. The test results from each stockpile can be used to estimate the results for a given combination of materials.

7. Determining an Initial Trial Binder Content for Each Trial Aggregate Gradation - Designers can either use their experience with the materials or the procedure given in Appendix X1 to determine an initial trial binder content for each aggregate trial blend.

> Note 6 - When using RAP, the initial trial asphalt content should be reduced by an amount equal to that provided by the RAP.

8. Compacting Specimens of Each Trial Gradation

8.1 Prepare replicate mixtures (Note 75) at the initial trial binder content for each of the chosen aggregate trial blends. From Table 1, determine the number of gyrations based on the design ESALs for the project.

> Note 75 - At least two replicate specimens are required, but three or more may be prepared if desired. Generally, 4500 to 4700 g of aggregate is usually sufficient for each compacted specimen with a height of 110 to 120 mm for aggregates with combined bulk specific gravities of 2.55 - 2.70, respectively.

8.2 Condition the mixtures according to PP2, and compact the specimens to N_{design} gyrations in accordance with TP4. Record the specimen height to the nearest 0.1 mm after each revolution.

8.3 Determine the bulk specific gravity (G_{mb})of each

of the compacted specimens in accordance with T166 or T275 as appropriate.

8.4 Determine the theoretical maximum specific gravity (G_{mm}) according to T209 of separate samples representing each of these combinations that have been mixed and conditioned to the same extent as the compacted specimens.

Note 86 - The maximum specific gravity for each trial mixture shall be based on the average of at least two tests.

9. Evaluating Compacted Trial Mixtures

9.1 Determine the volumetric requirements for the trial mixtures in accordance with MP2.

9.2 Calculate V_a and VMA at N_{design} for each trial mixture using Equations 2 and 3:

$$V_a = 100 \, x \left(1 - \left(\frac{G_{mb}}{G_{mm}} \right) \right) \quad (2)$$

$$VMA = 100 \, x \left(1 - \frac{G_{mb} P_s}{G_{sb}} \right) \quad (3)$$

where:

G_{mb} = the bulk specific gravity of the extruded specimen;
G_{mm} = the theoretical maximum specific gravity of the mixture;
P_s = the percent of aggregate in the mix; and
G_{sb} = the bulk specific gravity of the combined aggregate.

Note 97 - Although the initial trial binder content was estimated for a design air void content of 4.0 percent, the actual air void content of the compacted specimen is unlikely to be exactly 4.0 percent. Therefore, the change in binder content needed to obtain a 4.0 percent air void content, and the change in VMA caused by this change in binder content, is estimated. These calculations permit the evaluation of VMA and VFA of each trial aggregate gradation at the same design air void content, 4.0 percent.

9.3 Estimate the volumetric properties at 4.0 percent air voids for each compacted specimen.

9.3.1 Determine the difference in average air void content at N_{design} (ΔV_a) of each aggregate trial blend from the design level of 4.0 percent using Equation 4:

$$\Delta V_a = 4.0 - V_a \quad (4)$$

where:

V_a = air void content of the aggregate trial blend at N_{design} gyrations.

9.3.2 Estimate the change in binder content (ΔP_b) needed to change the air void content to 4.0 percent using Equation 5:

$$\Delta P_b = -0.4 \left(\Delta V_a \right) \quad (5)$$

9.3.3 Estimate the change in VMA (ΔVMA) caused by the change in the air void content (ΔV_a) determined in Section 9.3.1 for each aggregate trial blend, using Equation 6 or 7.

$$\Delta VMA = 0.2 (\Delta V_a) \quad (6) \qquad \text{If } V_a > 4.0$$

$$\Delta VMA = -0.1 (\Delta V_a) \quad (7) \qquad \text{If } V_a < 4.0$$

Note 108 - A change in binder content affects the VMA through a change in the bulk specific gravity of the compacted specimen (G_{mb}).

9.3.4 Calculate the VMA for each aggregate trial blend at N_{design} gyrations and 4.0 percent air voids using Equation 8:

$$VMA_{design} = VMA_{trial} + \Delta VMA \quad (8)$$

where:

VMA_{design} = the VMA estimated at a design air void content of 4.0 percent; and
VMA_{trial} = the VMA determined at the initial trial binder content.

9.3.5 Using the values of ΔV_a determined in Section 9.3.1 and Equation 9, estimate the relative density of each specimen at $N_{initial}$ when the design air void content is adjusted to 4.0 percent at N_{design}:

$$\%Gmm_{initial} = 100 \times \left(\frac{Gmbh_d}{Gmmh_i} \right) - \Delta V_a \qquad (9)$$

where:

$\%Gmm_{initial}$ = relative density at $N_{initial}$ gyrations at the adjusted design binder content;

h_d = height of the specimen after N_{design} gyrations, from the Superpave gyratory compactor, mm; and

h_i = height of the specimen after $N_{initial}$ gyrations, from the Superpave gyratory compactor, mm.

9.3.6 Estimate the percent of effective binder (Pbe_{est}) and calculate the dust-to-binder ratio ($P_{0.075}/P_{be}$) for each trial blend using equations 10 and 11:

$$be_{est} = - (Ps \times Gb) \ \frac{(Gse - Gsb)}{(Gse \times Gsb)} + Pb_{est}(1$$

where:

Pbe_{est} = the estimated effective binder content;
P_s = the aggregate content;
G_b = specific gravity of the binder;
G_{se} = the effective specific gravity of the aggregate;
G_{sb} = the bulk specific gravity of the combined aggregate; and
Pb_{est} = the estimated binder content.

$$P_{0.075} \ / \ P_{be} = \frac{P_{0.075}}{Pbe_{est}} \qquad (11)$$

where:

$P_{0.075}$ = the percent passing the 0.075 mm sieve.

9.3.7 Compare the estimated volumetric properties from each aggregate trial blend at the adjusted design binder content with the criteria specified in MP2. Select, as the design aggregate structure, that aggregate trial blend that best satisfies the criteria.

Note 11 9 - Table 2 presents an example of the selection of a design aggregate structure from three aggregate trial blends.

Note 12 0 -- Many aggregate trial blends will fail the VMA criterion. Generally, the $\%Gmm_{initial}$ criterion will be met if the VMA criterion is

satisfied. Subsection 12.1 gives a procedure for the adjustment of VMA.

Note 13 1 -- If the trial aggregate gradations have been chosen to cover the entire range of the gradation controls, then the only remaining solution is to make adjustments to the aggregate production or to introduce aggregates from a new source. The aggregates which fail to meet the required criteria will not produce a quality mix and should not be used. One or more of the aggregate stockpiles should be replaced with another material which produces a stronger structure. For example, a quarry stone can replace a crushed gravel, or crushed fines can replace natural fines.

10. Selecting the Design Binder Content

10.1 Prepare replicate mixtures (Note 7 5) containing the selected design aggregate structure at each of the following four binder contents: (1) the estimated design binder content, P_b(design); (2) 0.5 percent below P_b(design); (3) 0.5 percent above P_b(design); and (4) 1.0 percent above P_b(design).

10.1.1 From Table 1, determine the number of gyrations based on the design ESALs for the project.

10.2 Condition the mixtures according to PP2, and compact the specimens to N_{design} gyrations according to TP4. Record the specimen height to the nearest 0.1 mm after each revolution.

10.3 Determine the bulk specific gravity of each of the compacted specimens in accordance with T166 or T275 as appropriate.

10.4 Determine the theoretical maximum specific gravity (G_{mm}) according to T209, of each of the four mixtures using companion samples which have been conditioned to the same extent as the compacted specimens (Note 8 6).

10.5 Determine the design binder content which produces a target air void content (V_a) of 4.0 percent at N_{design} gyrations using the following steps:

10.5.1 Calculate V_a, VMA, and VFA at N_{design} using Equations 2, 3 and 12:

PP28

$$VFA = 100 \, x \left(\frac{VMA - V_a}{VMA} \right) \qquad (12)$$

10.5.2 Calculate the dust-to-binder ratio, using equation 13.

$$P_{0.075} \, / \, P_{be} = \frac{P_{0.075}}{P_{be}} \qquad (13)$$

where:

P_{be} = the effective binder content.

10.5.3 For each of the four mixtures, determine the average corrected specimen relative densities at $N_{initial}$ ($\%Gmm_{initial}$), using Equation 14.

$$\%Gmm_{initial} = 100 \, x \left(\frac{G_{mb}h_d}{G_{mm}h_i} \right) \qquad (14)$$

10.5.4 Plot the average V_a, VMA, VFA, and relative density at N_{design} for replicate specimens versus binder content.

Note 142 - All plots are generated automatically by the Superpave software. Figure 2 presents a sample data set and the associated plots.

10.5.5 By graphical or mathematical interpolation (Figure 2), determine the binder content to the nearest 0.1 percent at which the target V_a is equal to 4.0 percent. This is the design binder content (P_b) at N_{design}.

10.5.6 By interpolation (Figure 2), verify that the volumetric requirements specified in MP2 are met at the design binder content.

10.6 Compare the calculated percent of maximum relative density with the design criteria at $N_{initial}$ by interpolation, if necessary. This interpolation can be accomplished by the following procedure.

10.6.1 Prepare a densification curve for each mixture by plotting the measured relative density at x gyrations, $\%Gmm_x$, versus the logarithm of the number of gyrations (see Figure 3).

10.6.2 Examine a plot of air void content versus binder content. Determine the difference in air voids between 4.0 percent and the air void content at the

nearest, lower binder content. Determine the air void content at the nearest, lower binder content at its data point, not on the line of best fit. Designate the difference in air void content as ΔV_a.

10.6.3 Using Equation 14, determine the average corrected specimen relative densities at $N_{initial}$ ($\%Gmm_{initial}$). Confirm that $\%Gmm_{initial}$ satisfies the design requirements in MP2 at the design binder content.

10.7 Prepare replicate (Note 75) specimens composed of the design aggregate structure at the design binder content to confirm that $\%Gmm_{max}$ satisfies the design requirements in MP2.

10.7.1 Condition the mixtures according to PP2, and compact the specimens according to TP4 to the maximum number of gyrations, N_{max}, from Table 1.

10.7.2 Determine the average specimen relative density at N_{max}, $\%Gmm_{max}$, by using Equation 15, and confirm that $\%Gmm_{max}$ satisfies the volumetric requirement in MP2.

$$\%Gmm_{max} = 100 \frac{G_{mb}}{G_{mm}} \qquad (15)$$

where:

$\%Gmm_{max}$ = relative density at N_{max} gyrations at the design binder content.

11. Evaluating Moisture Susceptibility

11.1 Prepare six mixture specimens (nine are needed if freeze-thaw testing is required) composed of the design aggregate structure at the design binder content. Condition the mixtures in accordance with PP2, and compact the specimens to 7 ± 1.0 percent air voids in accordance with TP4.

11.2 Test the specimens and calculate the tensile strength ratio in accordance with T283.

11.3 If the tensile strength ratio is less than 0.80, as required in MP2, remedial action such as the use of anti-strip agents is required to improve the moisture susceptibility of the mix. When remedial agents are used to modify the binder, retest the mix to assure compliance with the 0.80 minimum requirement.

12. Adjusting the Mixture to Meet Properties

12.1 Adjusting VMA - If a change in the design aggregate skeleton is required to meet the specified VMA, there are three likely options: (1) change the gradation (Note 15~~3~~); (2) reduce the minus 0.075 mm fraction (Note 16~~4~~); or (3) change the surface texture and/or shape of one or more of the aggregate fractions (Note 17~~5~~).

Note 15~~3~~ - Changing gradation may not be an option if the aggregate trial blend analysis includes the full spectrum of the gradation control area.

Note 16~~4~~ - Reducing the percent passing the 0.075 mm sieve of the mix will typically increase the VMA. If the percent passing the 0.075 mm sieve is already low, this is not a viable option.

Note 17~~5~~ - This option will require further processing of existing materials or a change in aggregate sources.

12.2 Adjusting VFA - The lower limit of the VFA range should always be met at 4.0 percent air voids if the VMA meets the requirements. If the upper limit of the VFA is exceeded, then the VMA is substantially above the minimum required. If so, redesign the mixture to reduce the VMA. Actions to consider for redesign include: (1) changing to a gradation that is closer to the maximum density line; (2) increasing the minus 0.075 mm fraction, if room is available within the specification control points; or (3) changing the surface texture and shape of the aggregates by incorporating material with better packing characteristics, e.g., less thin, elongated aggregate particles.

12.3 Adjusting the Tensile Strength Ratio - The tensile strength ratio can be increased by: (1) adding chemical anti-strip agents to the binder to promote adhesion in the presence of water; or (2) adding hydrated lime to the mix.

13. Report

13.1 The report shall include the identification of the project number, traffic level, and mix design number.

13.2 The report shall include information on the design aggregate structure including the source of aggregate, kind of aggregate, source and amount of RAP, required quality characteristics, and gradation.

13.3 The report shall contain information about the design binder including the source of binder and the performance grade.

13.4 The report shall contain information about the HMA including the percent of binder in the mix; the relative density; the number of initial, design, and maximum gyrations; and the VMA, VFA, V_{be}, V_{ba}, V_a, and dust-to-binder ratio.

14. Keywords - HMA mix design; volumetric mix design; Superpave.

Appendix X1
Calculating an Initial Trial Binder Content
for Each Aggregate Trial Blend
(Non-Mandatory Information)

X1.1 Calculate the bulk and apparent specific gravities of the combined aggregate in each trial blend using the specific gravity data for the aggregate fractions obtained in Subsection 6.6 and Equations X1.1 and X1.2:

$$G_{sb} = \frac{P_1 + P_2 + \ldots + P_n}{\dfrac{P_1}{G_1} + \dfrac{P_2}{G_2} + \ldots + \dfrac{P_n}{G_n}} \qquad \text{(X1.1)}$$

$$G_{sa} = \frac{P_1 + P_2 + \ldots + P_n}{\dfrac{P_1}{G_1} + \dfrac{P_2}{G_2} + \ldots + \dfrac{P_n}{G_n}} \qquad \text{(X1.2)}$$

where:

G_{sb} = the bulk specific gravity for the combined aggregate;

G_{sa} = the apparent specific gravity for the combined aggregate;

P_1, P_2, P_n = the percentages by mass of aggregates 1, 2, n; and

G_1, G_2, G_n = the bulk specific gravities (Eq. X1.1) or apparent specific gravities (Eq. X1.2) of aggregates 1, 2, n.

X1.2 Estimate the effective specific gravity of the combined aggregate in the aggregate trial blend using Equation X1.3:

$$G_{se} = G_{sb} + 0.8 \; (G_{sa} - G_{sb}) \qquad \text{(X1.3)}$$

where:

G_{se} = the effective specific gravity of the combined aggregate;

G_{sb} = the bulk specific gravity of the combined aggregate; and

G_{sa} = the apparent specific gravity of the combined aggregate.

Note X1.1 - The multiplier, 0.8, can be changed at the discretion of the designer. Absorptive aggregates may require values closer to 0.6 or 0.5.

Note X1.2 - The Superpave mix design system includes a mixture conditioning step before the compaction of all specimens; this conditioning generally permits binder absorption to proceed to completion. Therefore, the effective specific gravity of Superpave mixtures will tend to be close to the apparent specific gravity in contrast to other design methods where the effective specific gravity generally will lie near the midpoint between the bulk and apparent specific gravities.

X1.3 Estimate the volume of binder absorbed into the aggregate, V_{ba}, using Equations X1.4 and X1.5:

$$V_{ba} = W_s \left(\frac{1}{G_{sb}} - \frac{1}{G_{se}} \right) \qquad \text{(X1.4)}$$

where W_s, the mass of aggregate in 1 cm^3 of mix, g, is calculated as:

$$W_s = \frac{P_s \; (1 - V_a)}{\dfrac{P_b}{G_b} + \dfrac{P_s}{G_{se}}} \qquad \text{(X1.5)}$$

and where:

P_b = the mass percent of binder, in decimal equivalent, assumed to be 0.05;

P_s = the mass percent of aggregate, in decimal equivalent, assumed to be 0.95;

G_b = the specific gravity of the binder; and

V_a = the volume of air voids, assumed to be 0.04 cm^3 in 1 cm^3 of mix.

Note X1.3 - This estimate calculates the volume of binder absorbed into the aggregate, V_{ba}, and subsequently, the initial, trial binder content at a target air void content of 4.0 percent.

X1.4 Estimate the volume of effective binder using Equation X1.6:

$$V_{be} = 0.176 - [0.0675 \log(S_n)] \qquad \text{(X1.6)}$$

where:

V_{be} = the volume of effective binder, cm^3; and

S_n = the nominal maximum sieve size of the largest aggregate in the aggregate trial blend, mm.

Note X1.4 - This regression equation is derived from an empirical relationship between: (1) VMA and V_{be} when the air void content, V_a, is equal to 4.0 percent: V_{be} = VMA - P_a = VMA - 4.0; and (2) the relationship between VMA and the nominal maximum sieve size of the aggregate in MP2.

X1.5 Calculate the estimated initial trial binder (P_{bi}) content for the aggregate trial blend gradation using Equation X1.7:

$$P_{bi} = 100 \ x\left(\frac{G_b\left(V_{be} + V_{ba}\right)}{\left(G_b\left(V_{be} + V_{ba}\right)\right) + W_s}\right) \quad \text{(X1.7)}$$

where:

P_{bi} = the estimated initial trial binder content, percent by weight of total mix.

Table 1 - Superpave Gyratory Compaction Effort

Design ESALs[1] (million)	Compaction Parameters			Typical Roadway Application[2]
	$N_{initial}$	N_{design}	N_{max}	
< 0.3	6	50	75	Applications include roadways with very light traffic volumes such as local roads, county roads, and city streets where truck traffic is prohibited or at a very minimal level. Traffic on these roadways would be considered local in nature, not regional, intrastate, or interstate. Special purpose roadways serving recreational sites or areas may also be applicable to this level.
0.3 to < 3	7	75	115	Applications include many collector roads or access streets. Medium-trafficked city streets and the majority of county roadways may be applicable to this level.
3 to < 30	8	100	160	Applications include many two-lane, multilane, divided, and partially or completely controlled access roadways. Among these are medium to highly trafficked city streets, many state routes, US highways, and some rural Interstates.
≥ 30	9	125	205	Applications include the vast majority of the US Interstate system, both rural and urban in nature. Special applications such as truck-weighing stations or truck-climbing lanes on two-lane roadways may also be applicable to this level.

(1)   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.

(2)   As defined by A Policy on Geometric Design of Highways and Streets, 1994, AASHTO.

Note 18̶6 -   When specified by the agency and the top of the design layer is ≥ 100 mm from the pavement surface and the estimated design traffic level is ≥ 0.3 million ESALs, decrease the estimated design traffic level by one, unless the mixture will be exposed to significant mainline construction traffic prior to being overlaid. If less than 25% 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.

Note 19̶7 -   When the estimated design traffic level is between 3 to <10 million ESALs, the agency may, at its discretion, specify $N_{initial}$ at 7, N_{design} at 75, and N_{max} at 115.

Table 2 - Selection of a Design Aggregate Structure (Example)

Volumetric Property	Trial Mixture (19.0 mm nominal maximum aggregate) 20-Year Project Design ESALs = 5 million			Criteria
	1	2	3	
	At the initial trial binder content			
P_b (trial)	4.4	4.4	4.4	
%$Gmm_{initial}$ (trial)	88.1	87.8	87.1	
%Gmm_{design} (trial)	95.9	95.3	94.7	
V_a at N_{design}	4.1	4.7	5.3	4.0
VMA_{trial}	12.9	13.4	13.9	
	Adjustments to reach design binder content (V_a = 4.0% at N_{design})			
ΔV_a	-0.1	-0.7	-1.3	
ΔP_b	0.0	0.3	0.5	
ΔVMA	0.0	-0.1	-0.3	
	At the estimated design binder content (V_a = 4.0% at N_{design})			
Estimated P_b (design)	4.4	4.7	4.9	
VMA (design)	12.9	13.3	13.6	≥ 13.0
%$Gmm_{initial}$ (design)	88.2	88.5	88.4	≤ 89.0

Notes: The top portion of this table presents measured densities and volumetric properties for specimens prepared for each aggregate trial blend at the initial trial binder content.

None of the specimens had an air void content of exactly 4.0 percent. Therefore, the procedures described in Section 9 must be applied to: 1) estimate the design binder content at which V_a = 4.0 percent, and 2) obtain adjusted VMA and relative density values at this estimated binder content.

The middle portion of this table presents the change in binder content (ΔP_b) and VMA (ΔVMA) that occurs when the air void content (V_a) is adjusted to 4.0 percent for each aggregate trial blend.

A comparison of the VMA and densities at the estimated design binder content to the criteria in the last column shows that aggregate trial blend #1 does not have sufficient VMA (12.9 % versus a requirement of ≥ 13.0 %). Trial blend #2 exceeds the criterion for relative density at $N_{initial}$ gyrations (89.5 % versus a requirement of $\leq$ 89.0 %). Trial #3 meets the requirements for relative density and VMA and, in this example, is selected as the design aggregate structure.
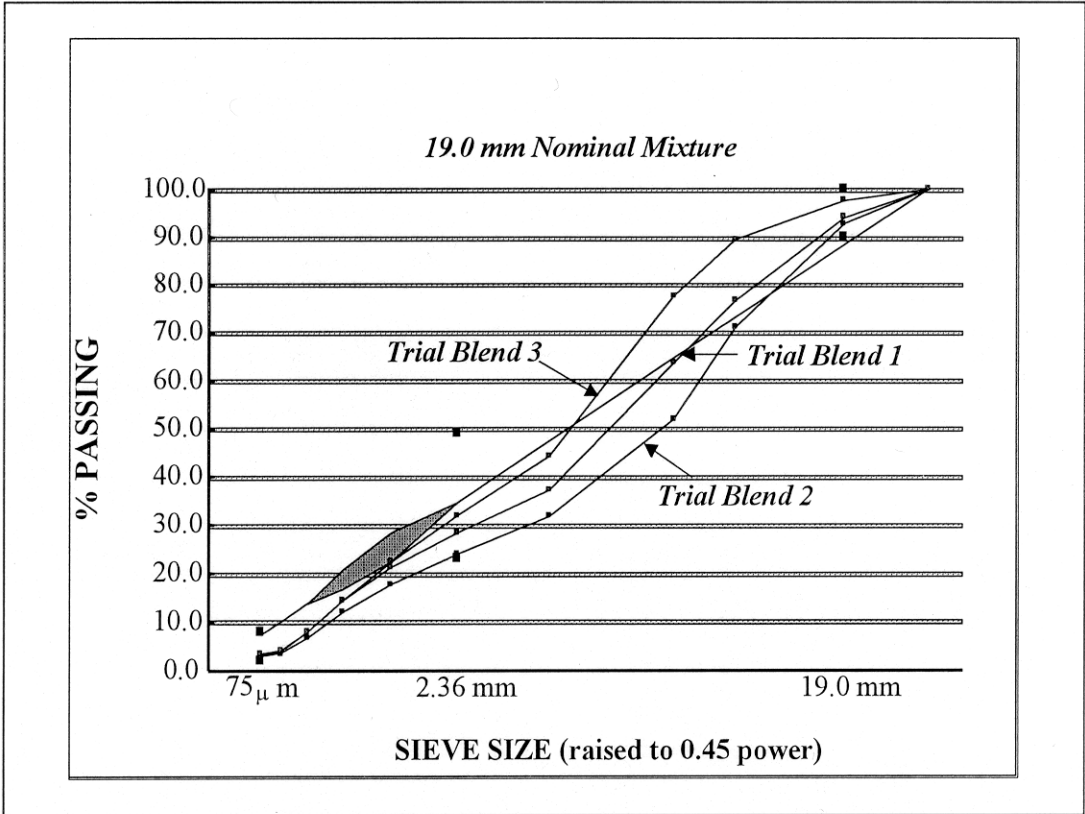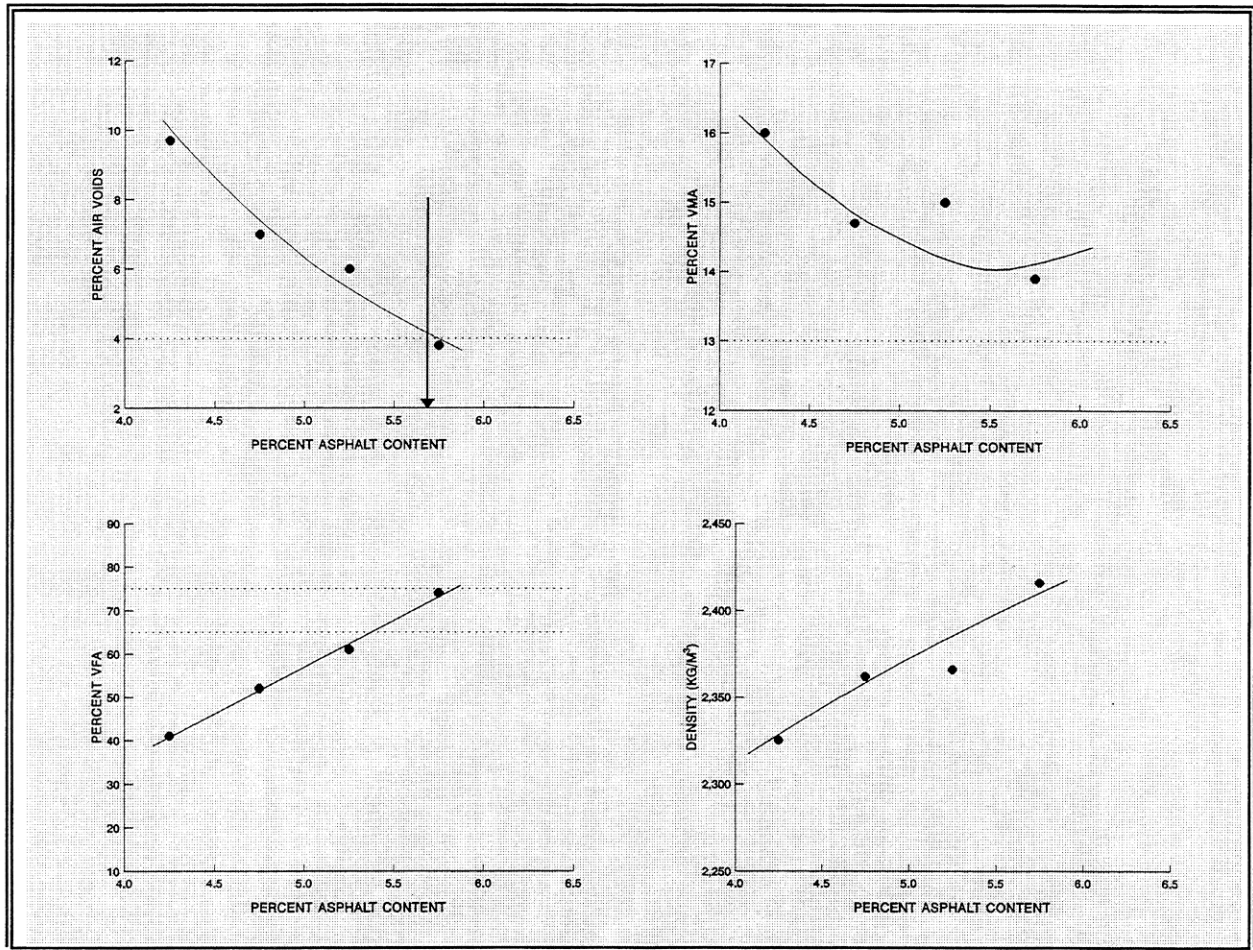
Figure 1 - Evaluation of the Gradations of Three Trial Blends (Example)

P_b (%)	V_a (%)	VMA (%)	VFA (%)	Density at N_{des} (kg/m^3)
4.3	9.5	15.9	40.3	2320
4.8	7.0	14.7	52.4	2366
5.3	6.0	14.9	59.5	2372
5.8	3.7	13.9	73.5	2412

In this example, the estimated design binder content is 4.8 percent; the minimum VMA requirement for the design aggregate structure (19.0 mm nominal maximum size) is 13.0 percent, and the VFA requirement is 65 to 75 percent.

Entering the plot of percent air voids versus percent binder content at 4.0 percent air voids, the design binder content is determined as 5.7 percent.

Entering the plots of percent VMA versus percent binder content and percent VFA versus percent binder content at 5.7 percent binder content, the mix meets the VMA and VFA requirements.

Figure 2 - Sample Volumetric Design Data at N_{des}
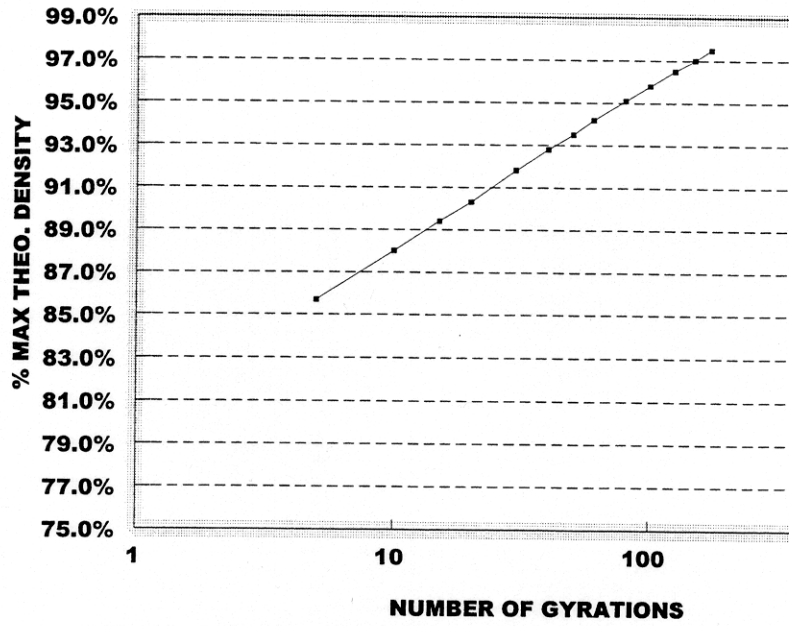
Figure 3 - Sample Densification Curve

F-A-25

Proposed Revisions to
Standard Test Method for the
Quantitative Extraction and Recovery of
Asphalt Binder from Hot Mix Asphalt (HMA)

AASHTO Designation TP2-94[1,2] (Reapproved 1996)

1. Scope

1.1 This standard describes a procedure for the extraction and recovery of asphalt binder from ~~hot mix~~ asphalt mixtures (both hot mix asphalt (HMA) and reclaimed asphalt pavement (RAP)) ~~samples~~ which has a minimal e~~a~~ffect on the physical and chemical properties of the asphalt binder recovered. It is intended for use when the physical or chemical properties or both of the recovered asphalt binder are to be determined. It can also be used to determine the quantity of asphalt binder in the HMA or RAP. Recovered aggregate may be used for sieve analysis.

1.2 This method is applicable to HMA sampled from the pavement, RAP sampled from the pavement or stockpile, HMA plant production, or laboratory fabricated HMA.

~~1.3 This method is not suitable for sieve analysis of recovered aggregate, since the aggregate undergoes prolonged grinding in the extraction device that will affect the aggregate gradation.~~

1.3̶4̶ This procedure may involve hazardous materials, operations and equipment. This procedure 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 determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 AASHTO Standards

M231	Specification for Standard Masses and Balances Used in the Testing of Highway Materials
T110	Moisture or Volatile Distillates in Bituminous Pavement Mixtures
T168	Method of Sampling Bituminous Paving Mixtures

2.2 ASTM Standards

D5361	Sampling Compacted Bituminous Mixtures for Laboratory Testing

3. Terminology

3.1 asphalt binder - an asphalt-based cement that is produced from petroleum residue either with or without the addition of non-particulate organic modifiers

4. Summary of Method - The ~~HMA sample~~ asphalt mixture is repeatedly washed and filtered with solvent ~~toluene and toluene with 15 percent ethanol~~ in an extraction/filtration apparatus. Each filtrate is distilled under vacuum in a rotary evaporator with the asphalt remaining in the flask. After recovery of the final filtrate, the solution is concentrated to about 300 mL and centrifuged to remove aggregate fines. The decanted solution is distilled under vacuum to remove the extraction solvents. Nitrogen gas is introduced during the final phase of distillation to drive off any remaining traces of solvents. The quantity of asphalt binder in the asphalt mixture~~HMA~~ is calculated (optional) and the recovered asphalt (distillation residue) sample is subjected to further physical and chemical testing as required. The recovered aggregate can then be used for sieve analysis, if desired.

5. Significance and Use - This method is used for obtaining recovered asphalt binder residue samples from asphalt mixture~~HMA~~ samples for further physical and chemical analyses, and for optional calculation of asphalt binder content ~~in HMA samples~~.

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[1] This standard is based on SHRP Product 1004.
[2] Approved in October 1994, this provisional standard was first published in March 1995.

6. Apparatus

6.1 Extraction Vessel - The extraction vessel shall be a device as shown in Figure 1, and shall have a 130-mm long piece of 150-mm I.D. Schedule 80 aluminum pipe or Schedule 80, grade 304 stainless steel pipe (Figure 2) with removable top and bottom 13-mm thick aluminum or stainless steel plates. The top plate (Figure 3) shall have a mixing motor mount and 19-mm port for adding solvent. The bottom plate (Figure 4) shall be equipped with a quick connect fitting. Four 100-mm by 25-mm baffles (Figure 5) shall be mounted in the extraction vessel followed by ~~a 2.00-mm stainless steel screen, glass wool plug, 0.203-μm filter, and 2.00-mm stainless steel backup screen.~~ 3-mm aluminum ring, 2-mm (#10) mesh screen, spacer (Figure 6), 0.3-mm (#50) mesh screen, another spacer, 0.075-mm (#200) mesh screen, then another 2-mm (#10) mesh screen, as shown in Figure 1.

> Note 1 - Vessel available through Pass Industries Ph# (606)881-0205 has proven acceptable for these requirements.

6.2 In-line ~~Fine~~ filter - The in-line ~~fine~~ filter apparatus shall be a cartridge type with 20-μm retention and at least 820-cm^3 effective filter area. The filter apparatus shall be able to be removed from the system to accommodate weighing before and after procedure. The filter shall be capable of withstanding heat up to 135°C without degradation in order to accommodate oven drying of the filter apparatus. ~~as shown in Figure 6, shall consist of a top and bottom (Figure 7), each fabricated from 13-mm diameter aluminum plate, which hold a 0.025-μm (1 micron) woven polypropylene filter and a 2.00-mm (#10) stainless steel backup screen.~~

> Note 2 - Whatman Polycap™ 75 HD Catalog number 6703-7521 or equivalent is a suitable filter.

6.3 ~~Suction flask, 500 mL~~ Two (2) filtrate flasks with tubulation, 1000mL

6.4 Round bottom flasks, 1000 mL and cork stands

6.5 Gas flowmeter, capable of indicating a gas flow up to 1000 mL/minute

6.6 Rotary evaporator device, ~~Buchi Rotavapor RE-111A,~~ with transfer and purge tubes, capable of holding a recovery flask in oil at a 15 degree angle and rotating at 40 r/min

> Note 3 - The Buchi Rotavapor RE-120 has proven acceptable for these requirements.

6.7 Hot oil bath, capable of heating oil to 180°C

6.8 Single speed mixing motor, 150 W (1/5 hp), 30 r/min

6.9 Centrifuge, batch unit capable of exerting a minimum centrifugal force of 770 times gravity

6.10 Wide-mouth centrifuge bottles, 250 mL.

6.11 Oven, capable of maintaining a temperature of 110 $\pm$ 5°C

6.12 Balance, of suitable capacity meeting the requirements of M231 for Class G2 balances

6.13 Thermometer, having a range of ~~-~~230 to 300°C

6.14 Utilities - Vacuum source and cooling water source.

6.15 Scale (optional) - having a capacity of 12 kg or more, sensitive to 0.1 g or less, and accurate within 0.1% of the test load at any point within the range of use for this test. Within any 100-g range of test load, a difference between readings shall be accurate within 0.1 g.

7. Materials and Reagents

7.1 6-mm diameter polypropylene tubing -- varying length, for transferring solution throughout the procedure ~~-- 430-mm long, for the rotavapor transfer tube -- 585-mm long, for the rotavapor purge tube~~

> Note 4~~1~~ - To avoid contamination of the sample due to solvent degradation of the tubing, do not substitute Nalgene or rubber tubing for the polypropylene tubing specified.

7.2 Copper tubing, of an amount and size adequate to connect the apparatus as shown in Figures 6 ~~8 or 9.~~

> ~~Note 2 - The quantity of copper tubing needed will be dependent upon the space used to set up the apparatus.~~

~~7.3 Woven Polypropylene Filter Cloths -- coarse filter cloth made from 2 by 2 twill weave monofilament woven polypropylene having a~~

~~0.203-μm (8 micron) or 0.0142 m3/minute (5 CFM)~~
~~rating and fine filter cloth made from oxford weave~~
~~multifilament woven polypropylene, having a 0.025 to~~
~~0.051-μm (1-2 micron) or 0.00142 m3/minute (0.5~~
~~CFM) rating~~

~~7.4 Glass Wool, borosilicate~~

~~7.5 Stainless steel screen, 2.00 mm (#10)~~

~~7.6 Toluene, reagent grade~~

~~7.7 Ethanol, absolute~~

7.3 Solvent

7.3.1 n-Propyl Bromide

7.3.2 or, Trichloroethylene, reagent grade

7.3.3 or, Toluene, reagent grade. If using Toluene, combine with Ethanol, absolute, in proportions of 85% Toluene and 15% Ethanol after the third wash (in section 12.2)

7.8 Nitrogen gas, at least 99.95 percent pure, in a pressurized tank, with a pressure-reducing regulator valve

8. Hazards - Use solvents only under a fume hood or with an effective surface exhaust system in a well-ventilated area and observe the manufacturer's recommended safety precautions when using compressed nitrogen.

9. Sampling - Obtain asphalt mixture~~HMA~~ samples in accordance with T168. When sampling from a compacted roadway, remove specimens from the roadway in accordance with ASTM D5361. When sampling RAP, refer to ASTM D75 for aggregate sampling.

10. Preparation of Apparatus

10.1 Preparing the Extraction Vessel - Install the baffles piece and other internal parts in the order shown in Figure 1. ~~place the metal screen downstream~~ ~~of the baffle. Cut several pieces of glass wool and~~ ~~pack them in the space between the screen and the~~ ~~downstream end of the extraction vessel. Place the~~ ~~gaskets, filter and aluminum end piece on extraction~~ ~~vessel, as shown in Figure 1.~~ Tightly and evenly

fasten the bottom~~end~~ piece (with quick connect) of the vessel with wing nuts or hexagonal nuts.

10.2 Preparing the Rotary Evaporator - Turn on the cooling water. Turn on the oil bath and set the temperature to $100 \pm 2.5°C$. Place six 3-mm glass boiling beads in a 1000 mL round bottom flask. Attach this~~e~~ recovery flask to the rotary evaporator and immerse approximately 38 mm of the flask into the oil bath. Set the angle of the recovery flask from the horizontal to the bath at 15 degrees. Set the flask rotation at 40 r/min. Clamp the empty condensate flask onto the condenser. Attach the transfer tube inside the neck of the rotary evaporator. ~~Apply a~~ ~~vacuum of 93.3 ± 0.7 kPa (700 ± 5 mm Hg) to the~~ ~~rotary evaporator.~~ Attach the filtrate transfer line to the external fitting on neck of rotary evaporator.

11. Standardization

11.1 At least every six months, verify the calibration of the oil bath temperature detector by using a certified mercury in glass thermometer of suitable range that is accurate to $\pm 0.2°C$. Immerse the thermometer in the oil bath close to the thermal detector and compare the temperature indicated by the certified thermometer to the temperature setting for the oil bath. If the temperature indicated by the thermal detector does not agree with the certified thermometer within $\pm 0.5°C$, perform additional calibration or maintenance.

11.2 At least every six months, use a mercury manometer or other certified pressure measurement device to verify calibration of the vacuum indicator. If the vacuum indicator and the certified pressure measurement device do not agree within ± 0.1 kPa, perform additional calibration or maintenance~~maintainance~~.

11.3 At least every six months, verify the rotational velocity of the rotary evaporator.

11.4 At least every six months, verify the flow rate of the nitrogen flow meter.

12. Procedure

12.1 Sample Preparation

12.1.1 If a sample of ~~HMA~~asphalt mixture is not sufficiently soft to separate with a spatula or trowel, place the sample in

a large, flat pan and warm it in a oven at $110 \pm 5°C$ only until it can be handled or mixed.

12.1.2 Split or quarter the loose asphalt mixture~~HMA~~ sample until an amount of the~~HMA~~ sample that will yield approximately 50 to 60 g of extracted asphalt binder is obtained (typically approximately 1000g of asphalt mixture). ~~If the asphalt binder content is to be determined, record the mass of the HMA sample obtained and recovery flask to the nearest 0.1 g. If more than approximately 60 g is required for testing, use multiple extractions and recoveries.~~

Note 5~~3~~ - This procedure works best when recovering~~for quantities of asphalt binder~~ less than 60 g of asphalt binder. Therefore, if the asphalt binder content of the mix is already known, then the mass of the original~~HMA~~ sample required is that which yields about 50 to 60 g of asphalt binder.

Note 6~~4~~ - The maximum aggregate size in the test specimen will affect the calculated asphalt content. If the calculated results from this standard are used to represent the asphalt content in the asphalt mixture~~HMA~~ from which the sample was obtained, use a minimum mass of test specimens for calculations that will ensure that inclusion or removal of one maximum size particle will not change the calculated asphalt content by more than 0.05 percent. This may require testing multiple test specimens.

12.1.3 If the asphalt binder content is to be determined, obtain a separate test specimen from the asphalt mixture~~HMA~~ sample, determine the moisture content in accordance with T110 and record the mass percent of water in the test specimen.

12.2 Extraction and Filtration

12.2.1 Place the asphalt mixture~~HMA~~ sample in the extraction vessel. Put the gasket and the upstream end piece on the vessel and fasten the wing nuts tightly and evenly, creating a secure seal.

12.2.2 Charge 600 mL of solvent~~toluene~~ through the 19-mm port on the upstream end of the extractor. Blanket the interior of the extraction vessel by injecting nitrogen through the upstream port at a rate of 1000 mL/min for 1 minute. Close the port with the threaded plug. Attach the extractor to the motor. Start the motor and mix for 5 ± 1 minutes at 30 r/min. Turn off the motor.

12.2.3 Remove the extractor, place it on a stand and attach the quick connect fitting to the first filtrate receiving flask. Make sure the filtrate transfer line is closed. Remove the upstream port plug and blanket the extractor with nitrogen at a rate of 400 mL/min while drawing the asphalt/solvent solution into the first flask~~filtering~~. Apply 93.3 ± 0.7 kPa (700 ± 5 mm Hg) vacuum to the first filtrate receiving flask to draw the material from the vessel. Continue drawing the solution into the first flask until there is no noticeable amount of solution exiting the vessel. ~~Filter until the filtrate flow rate is below 10 mL/min.~~ Turn off the vacuum.

12.2.4~~3.1~~ Filtering through the in-line cartridge filter~~If using the fine filter~~, switch the vacuum to the~~a~~ second filtrate receiving flask and apply 93.3 ± 0.7 kPa (700 ± 5 mm Hg) vacuum. Filter until there is no noticeable amount of solution remaining in the first flask or the filter.~~the filtrate flow rate is below 10 mL/min.~~ Turn off the vacuum.

12.2.5~~4~~ After filtration, open the filtrate transfer valve on the second receiving flask and allow the solution to flow from the filtrate receiving flask to the recovery flask. Continue the transfer until the filtrate receiving flask is empty or the recovery flask is about 2/3 full, then, begin the primary distillation.

12.2.6~~5~~ After the distillation is started, d~~Disconnect~~ the extractor from the quick connect fitting. Repeat the extraction procedure. For the second ~~and third~~ washes use 400 ± 10 mL of ~~toluene~~solvent and mix/rotate for 10 ± 1 minutes. For all subsequent washes (Note 7~~5~~), use 400 ± 10 mL of ~~toluene with 15 volume percent ethanol~~ solvent and mix for 30 to 35 minutes. ~~In addition, mix the second wash for ten ± 1 minutes and all subsequent washes for a minimum of 30 minutes.~~

Note 7~~5~~ - ~~It is suggested that a~~After the third wash, the condensate from the primary distillation step may be used for the extraction solvent. Recycling solvent in this manner allows the entire procedure to use approximately 1500 mL solvent~~toluene~~.

12.2.7~~6~~ Proceed to the final recovery step (12.4) ~~if~~ when the filtrate flowing through the transfer tube, after a 30 minute wash, is a light brown color. A minimum of three washes is required.

12.3 Primary Distillation

12.3.1 Close the filtrate transfer valve line and distill

TP2

solvent at 100 $\pm$ 2.5°C (oil bath temperature) and 93.3 $\pm$ 0.7 kPa (700 $\pm$ 5 mm Hg) vacuum.

12.3.2 If after the primary distillation step the condensate flask is over half full, empty the flask. Save this solvent for use in subsequent washes (Note 75). After primary distillation of each filtrate, maintain vacuum, temperature, flask rotation, and

cooling water. Repeat the primary distillation after each filtration (Note 86).

> Note 86 - It is important to concentrate the asphalt in the recovery flask after each wash and at a low temperature. This minimizes the temperature and the time spent in dilute solution and, therefore, minimizes asphalt hardening in solvent.

12.3.3 If desired, after primary distillation of the first three filtrates, remove the recovery flask (which should contain only small amounts of solvent) and set it aside. Replace it with another 1000 mL round bottom flask containing six 3-mm diameter glass boiling beads. Carry out the remaining primary distillations using the new recovery flask. Pour the contents of the current recovery flask into the original recovery flask. Attach the original recovery flask to the rotary evaporator.

12.4 Final Extraction and Recovery

12.4.1 Distill the contents of the recovery flask until it is about 1/3 full.

12.4.2 Turn off the vacuum, then clean and dDisconnect the recovery flask and pour the contents into the centrifuge bottles using a funnel and screen to prevent the boiling beads from entering the bottles. Fill the bottles so that their masses are equal. Wash any remaining residue from the recovery flask into the centrifuge bottles. Increase the oil bath temperature to 174 $\pm$ 2.5°C. Centrifuge the bottles at 3600 r/min for 25 minutes.

12.4.3 Empty the centrifuge bottles back into the recovery flask Decant the asphalt binder solvent solution into the recovery flask and add six 3-mm diameter glass boiling beads. Re-aAttach the flask to the rotary evaporator. Disconnect the transfer tube from the rotary evaporator and replace it with the gas purge tube. Disconnect the filtrate transfer line from the external rotary evaporator neck fitting and replace it with the nitrogen gas line. Apply 93.3 $\pm$ 0.7 kPa (700 mm Hg) vacuum. Lower the flask approximately

38 mm into the oil bath.

12.4.4 Distill the solvent.

12.4.5 When the condensation rate falls below 1 drop every 30 seconds, introduce nitrogen gas at a rate of 1000 mL/minute. Maintain the gas flow, vacuum and bath temperature for 30 $\pm$ 1 minutes to reduce the residual solvent concentration to near zero. Complete removal of residual solvent is very important for obtaining accurate asphalt properties.

12.4.6 Shut down the oil bath, flask rotation, vacuum, gas flow, and cooling water. Remove the evaporating flask. If the asphalt binder content is to be determined, determine and record the mass of the recovered asphalt binder to the nearest 0.1 g. Pour the asphalt into a sample tin using a screen to prevent the boiling beads from entering the tin.

13. Calculations (Optional)

13.1 Calculate the percent asphalt binder in the HMA using the following formula:

$$a = [w3 / (w1 - w2)](100)$$

where:

$$w2 = (w1)(wpercent/100)$$

and where:

a = percent asphalt in the test specimen
w1 = mass of test specimen in grams
w2 = mass of water in test specimen in grams
wpercent = mass percent of water
w3 = mass of asphalt in test specimen in grams

13. Determination of Asphalt Binder Content (Optional)

13.1 When a determination of asphalt binder content is desired, use the following procedure:

Before section 12.2.1:

- determine mass of mixture sample
- determine mass of cartridge filter
- determine mass of centrifuge bottles

After section 12.4.3:

- dry centrifuge bottles, in-line filter and opened

vessel (including inserts) to constant mass
- determine mass of fine material in centrifuge bottles (dry - original)
- determine mass of fine material in filter (dry - original)
- determine mass of all aggregate material in vessel (scrape/brush all screens, etc.)

Asphalt content % =
$$\frac{\text{Original sample -(Recovered aggr} + \Delta \text{Bottles} + \Delta \text{filter})}{\text{Original sample}}$$

14. Report

14.1 Report the source of the test sample.

14.2 Report the following, if the asphalt binder content is to be determined:

14.2.1 the mass of test specimen to the nearest gram,

14.2.2 the mass percent of water in the companion test specimen to the nearest 0.01 percent,

14.2.3 the mass of asphalt binder in the test specimen to the nearest gram,

14.2.4 the percent asphalt binder in the test sample to the nearest 0.01 percent,

15. Precision and Bias

15.1 Precision - The research required to develop precision values has not been conducted.

15.2 Bias - The research required to establish the bias of this method has not been conducted.

16. Key Words - extraction, recovery, asphalt binder, rotary evaporator
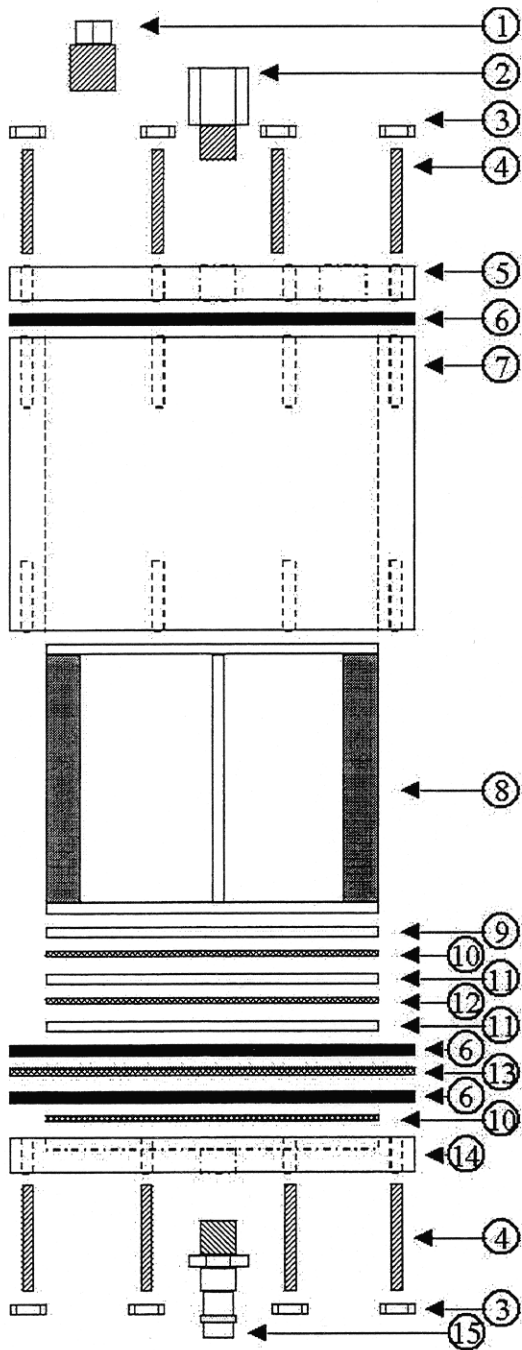
1-   1- ISO 12RT (3/4 in. NPT) plug

2-   ISO 8RT (1/2 in. NPT) fitting with I.D. hole for motor shaft

3-   12 M5 x 0.5 nuts

4-   12 M5 x 0.5 x 50 mm studs

5-   extraction vessel top

6-   3 Viton gaskets 3 mm thick, 16 mm width with holes to fit over studs

7-   extraction vessel housing

8-   aluminum baffle

9-   aluminum ring 3 mm thick 148 mm O. D., 10 mm width

10-   stainless steel #10 screen

11-   metal spacers

12-   # 50 screen

13-   # 200 screen

14-   extraction vessel bottom

15-   ISO 4RT (1/4 in. NPT) quick connect fitting

Figure 1- Extraction Vessel
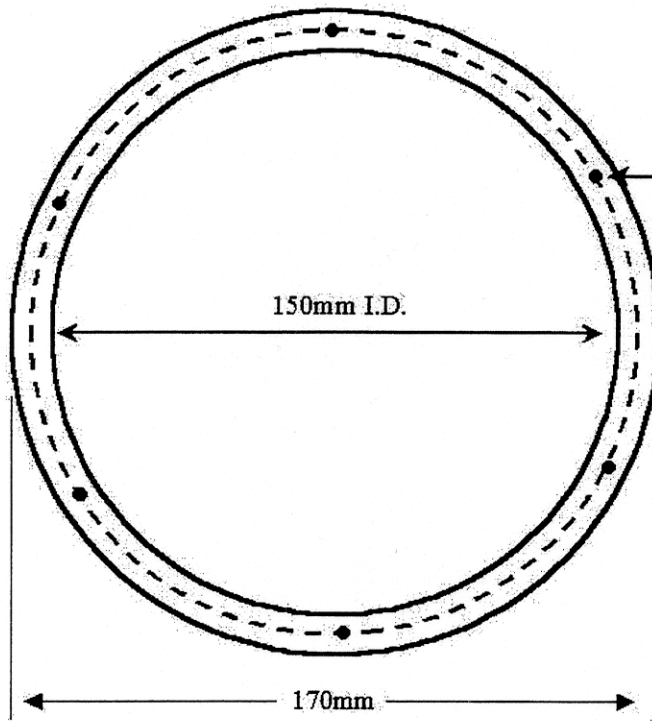
6 holes, equally spaced on a
160mm diameter, drilled and
tapped M5 x 0.5, 13mm
deep, top and bottom
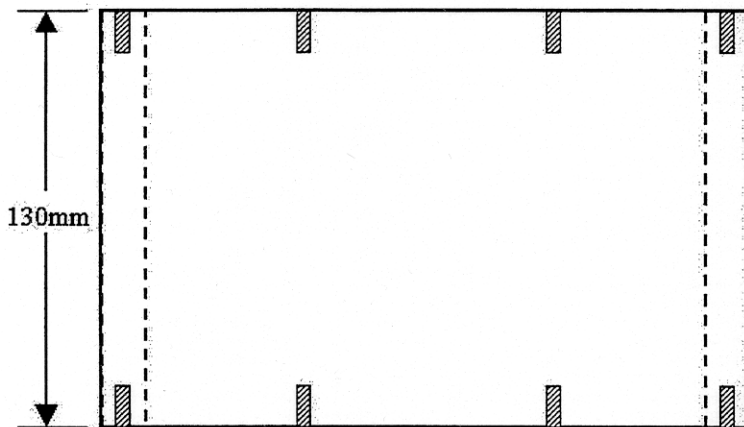
150mm I.D.

170mm

130mm

Notes:

All dimensions in mm

Not to scale

Unless otherwise indicated
assume a tolerance of 0.2 mm

Schedule 80 Aluminum or Schedule 80 Stainless Steel, Grade 304

Figure 2- Extraction Vessel Housing
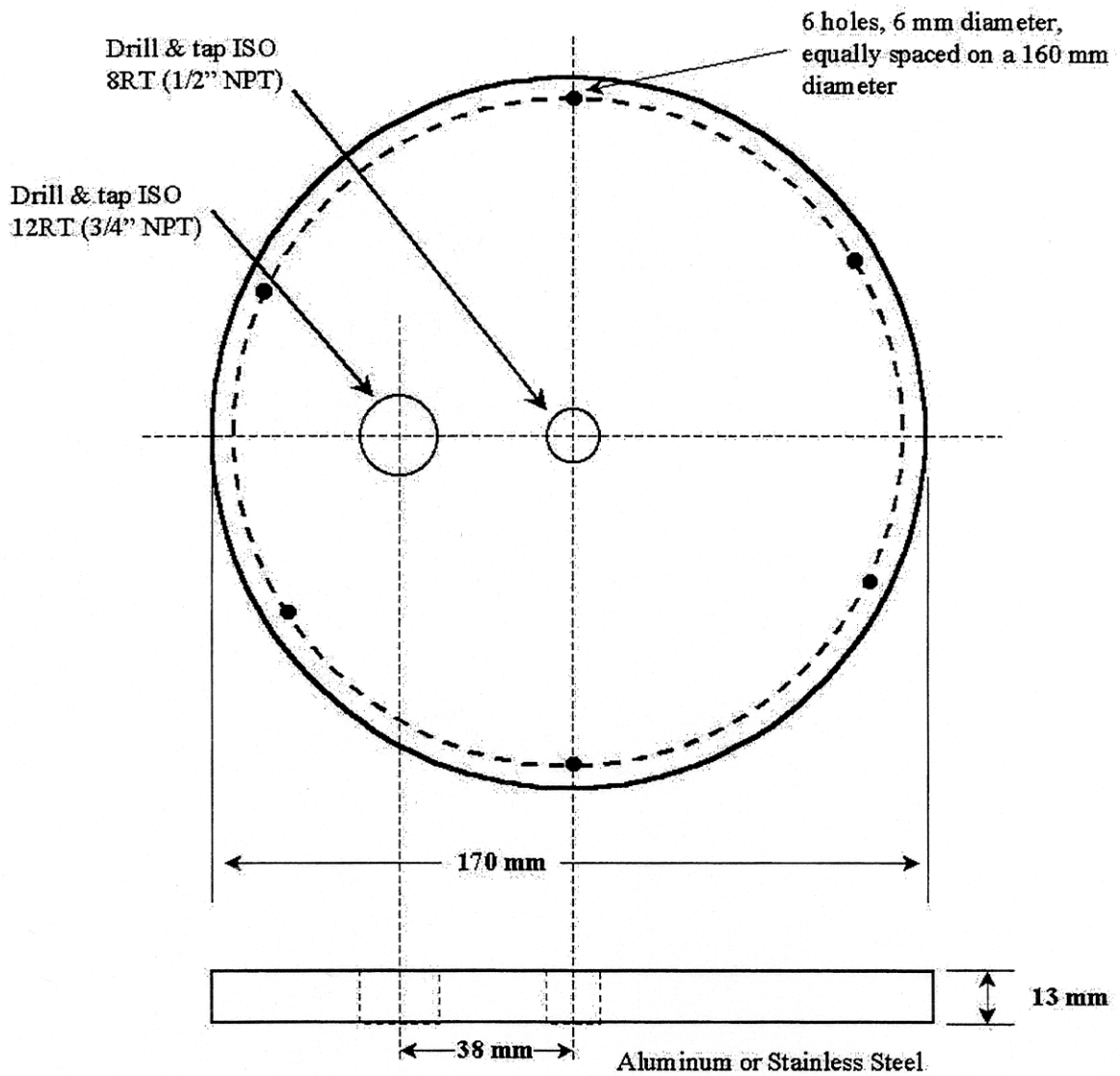
Drill & tap ISO
8RT (1/2" NPT)

Drill & tap ISO
12RT (3/4" NPT)

6 holes, 6 mm diameter,
equally spaced on a 160 mm
diameter

170 mm

13 mm

38 mm

Aluminum or Stainless Steel

Notes:

All dimensions in mm

Not to scale

Unless otherwise indicated
assume a tolerance of 0.2 mm

Figure 3- Extraction Vessel Top Plate
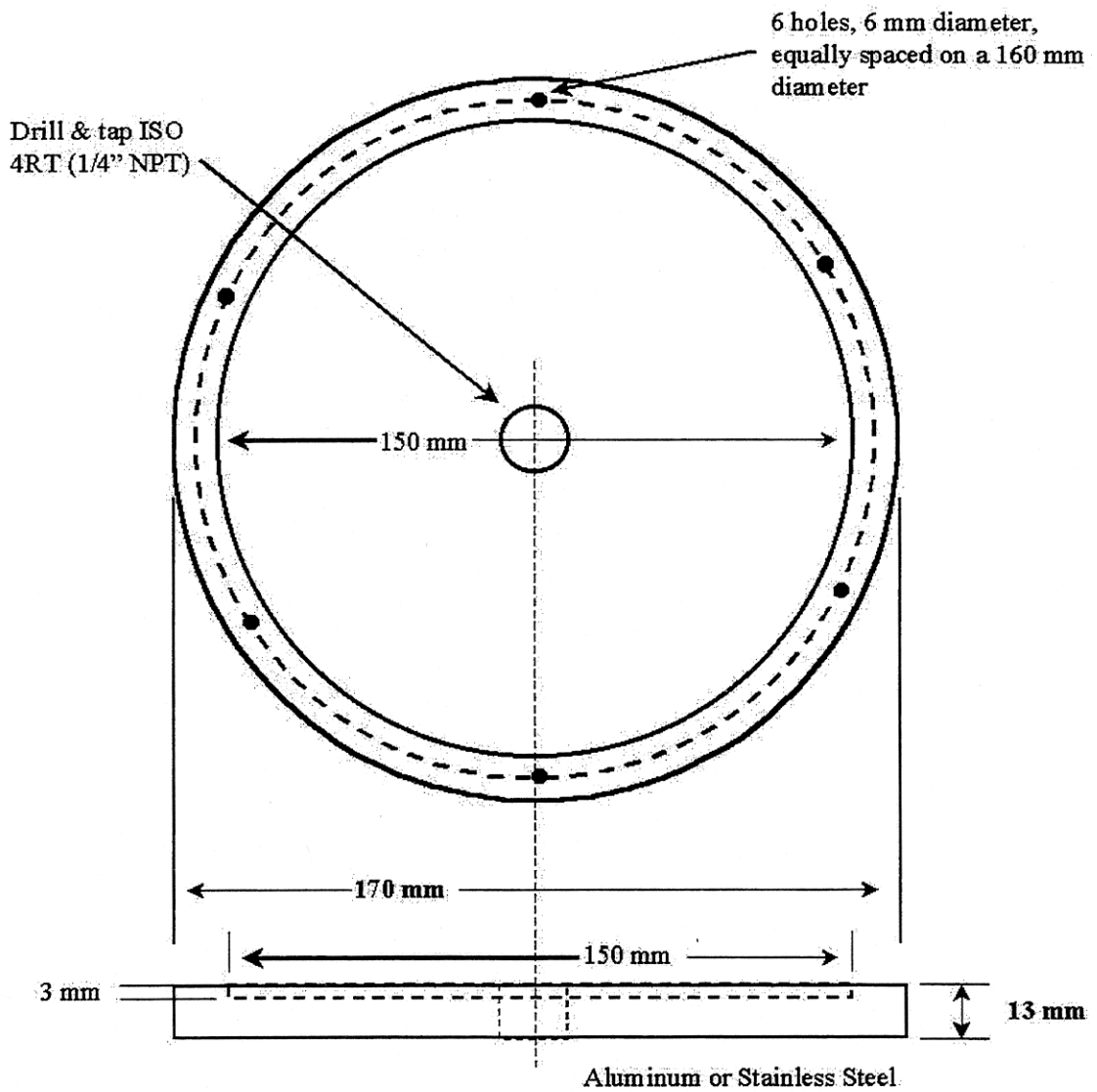
6 holes, 6 mm diameter, equally spaced on a 160 mm diameter

Drill & tap ISO 4RT (1/4" NPT)

150 mm

170 mm

150 mm

3 mm

13 mm

Aluminum or Stainless Steel

Notes:

All dimensions in mm

Not to scale

Unless otherwise indicated assume a tolerance of 0.2 mm

Figure 4- Extraction Vessel Bottom Plate

2 aluminum rings 148
mm O.D., 128 mm I.D.

Weld

148 mm
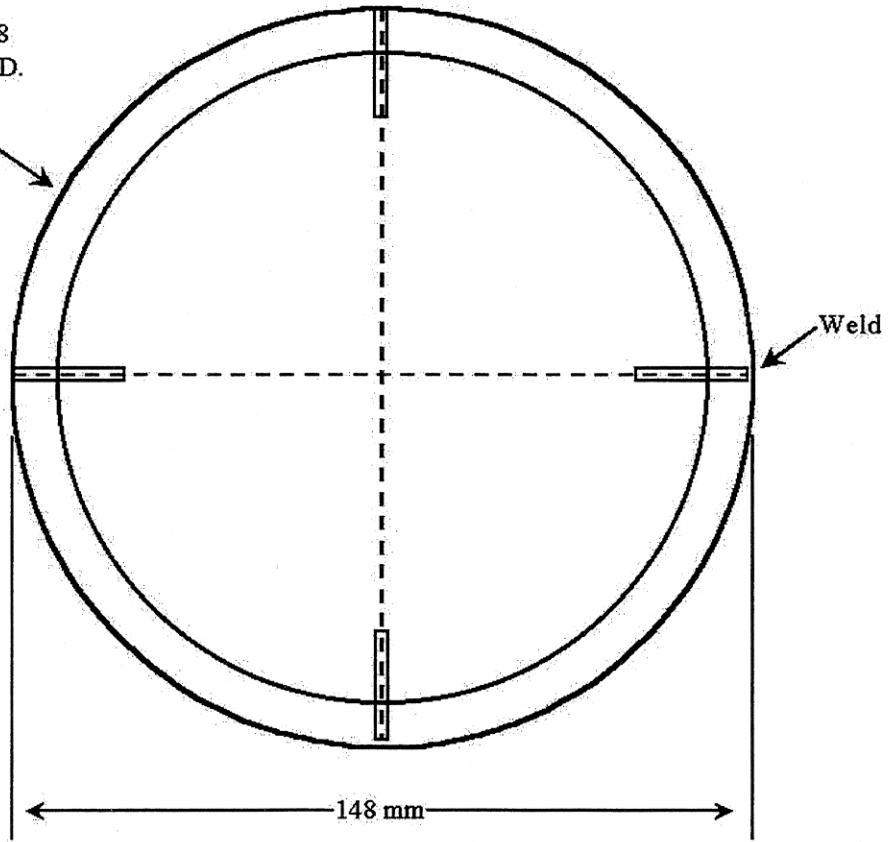
3 mm

4 aluminum plates 100
mm x 25 mm x 3 mm

100 mm
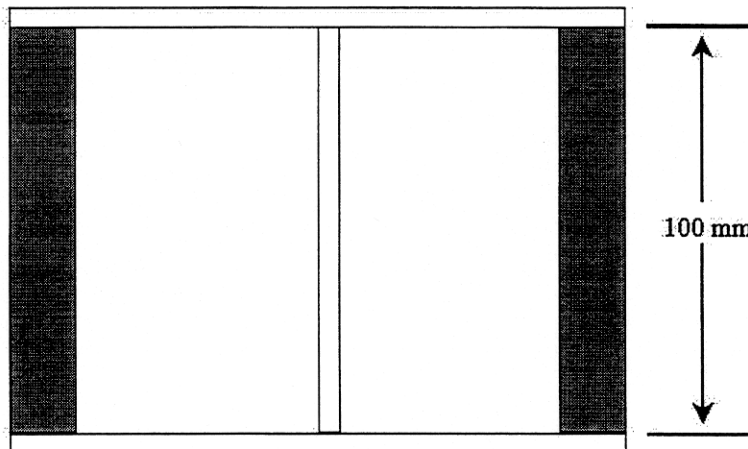
Figure 5- Extraction Vessel Baffle

12.9 mm I.D.

148 mm

Aluminum or Stainless Steel
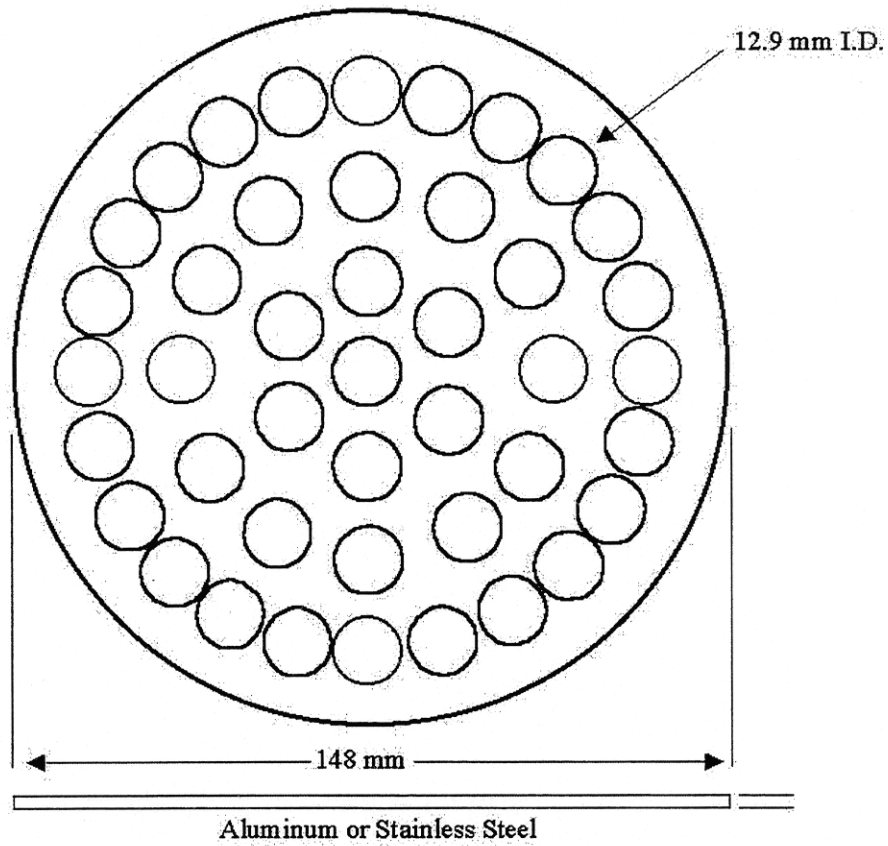
3 mm

Figure 6- Extraction Vessel Spacer
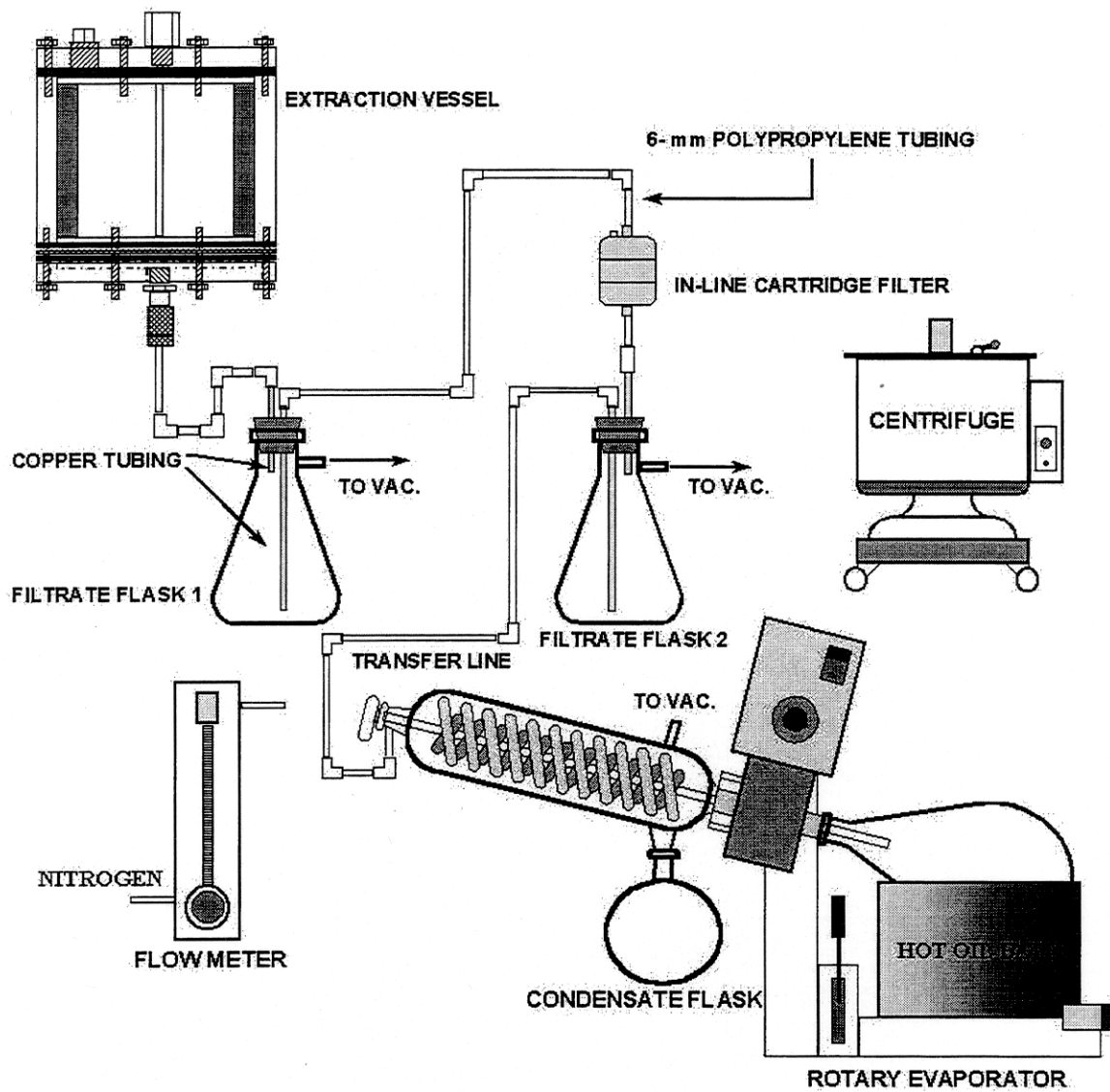
Figure 7- Extraction and Recovery Apparatus

APPENDIX F: APPENDIX B, Suggested Training Material Additions

Superpave Mixtures
with RAP

Conduct Sampling

↓

Perform Tests

↓

Determine Mean, Standard Deviation
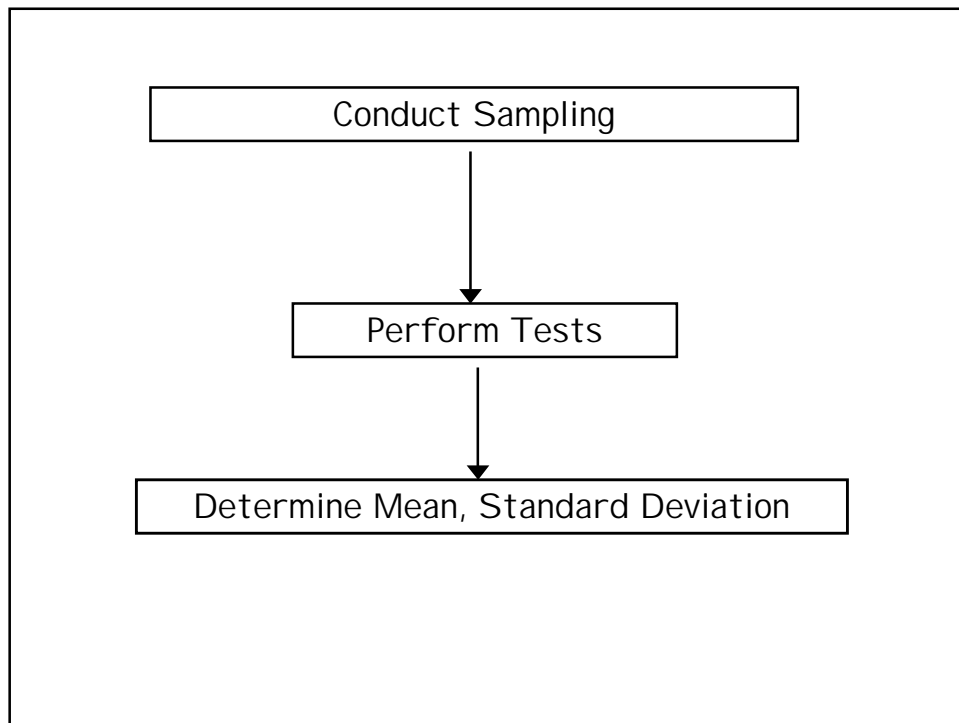
Evaluation of RAP

- Asphalt Content
- Aggregate Gradation
- Aggregate Properties
  - Consensus properties
- Binder Properties
  - RAP binder stiffness influences how much RAP can be used with minimal testing

RAP Aggregate Evaluation

- Extract and test
  - Gradation
  - Coarse aggregate angularity
  - Fine aggregate angularity
  - Flat and elongated particles
- Include in evaluation of consensus properties of trial blends
  - Evaluate sand equivalent on virgin aggregates only

RAP Binder Evaluation

- If using high percentages of RAP - see binder grade selection table
- Extract and recover binder according to AASHTO TP2 (revised)
- Determine high, intermediate and low critical temperatures for recovered RAP binder

Possible Binder Grade Selection Table

	RAP Percentage		
	Recovered RAP Grade		
Recommended Virgin Asphalt Binder Grade	PG xx-22 or lower	PG xx-16	PG xx-10 or higher
No change	<20%	<15%	<10%
One grade softer than normal (i.e., PG 58-28 instead of PG 64-22)	20 – 30%	15 – 25%	10 – 15%
Follow recommendations from blending charts	>30%	>25%	>15%

Steps in Mix Design (Superpave)

Gradation, Asphalt Content and Low Temperature Grade of Extracted Binder from RAP

↓

Gradation of New Aggregate

↓

Determine Combined Gradation in Recycled Mix

Steps in Mix Design (Superpave) (continued)

Determine Approximate Asphalt Demand of Combined Aggregate

↓

Determine Virgin Binder Grade

↓

Estimate initial trial binder content (Reduce added binder due to amount of RAP binder present)

Steps in Mix Design (Superpave) (continued)

Compact Trial Mixes with Superpave Gyratory Compactor

↓

Evaluate Mixtures and Select Job Mix Formula

Selection of PG Grade for New Binder

As shown on Table

- Tier 1, no change in binder grade.
- Tier 2, drop high and low grades by 6°.
- Tier 3, use blending charts.
- Tiers determined by low temperature stiffness of the RAP binder (may be estimated based on local experience)

Constructing a Blending Chart

- Use critical temperatures
- Determine Appropriate Grade of New Binder (Method A), or
- Determine Maximum and Minimum Amounts of RAP (Method B)

Data Needed for Blending Chart

- Target PG Grade
- Critical high, intermediate and low temperatures of recovered RAP binder
- And either
  - Critical high, intermediate and low temperatures of new (virgin) binder, or
 - Desired RAP content

Example of Method A - Blending at Known RAP Content

- Desired Final Binder Grade = PG64-22 or better
- Desired RAP Content = 30%
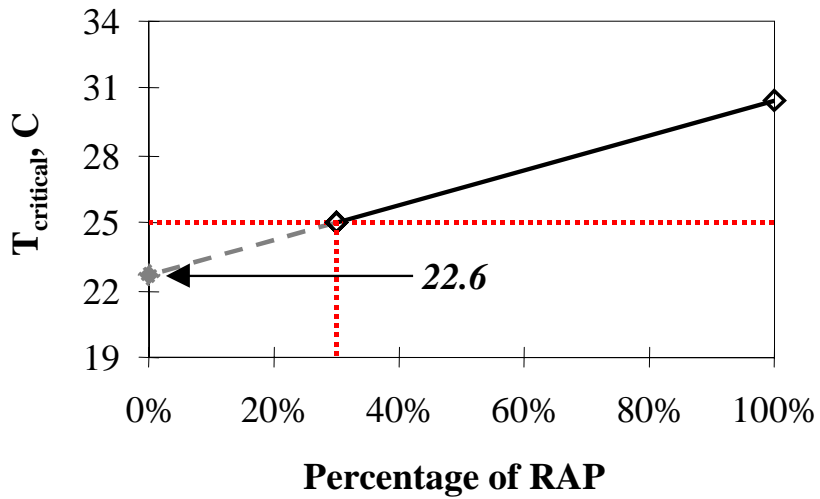- Recovered RAP Properties Measured

Critical Temperatures of Recovered RAP Binder

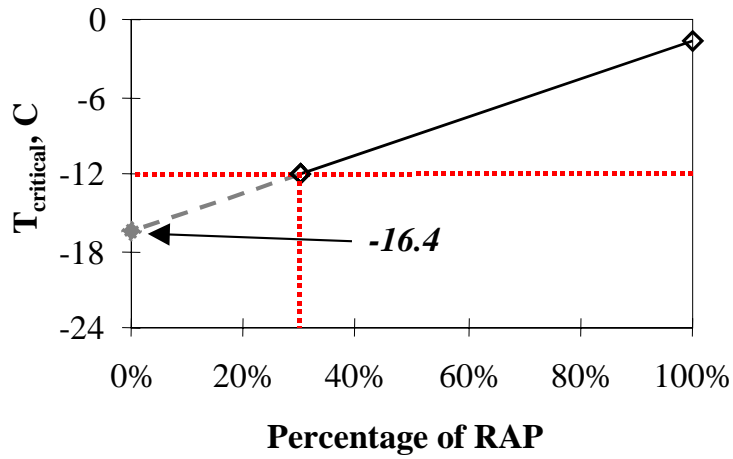| Property	Critical Temperature, C	
DSR G*/sinδ	High	**86.6**
DSR G*/sinδ	High	88.7
DSR G*sinδ	Intermed.	**30.5**
BBR S	Low	-4.5
BBR m-value	Low	**-1.7**
PG	Actual	PG 86-11
	MP1	PG 82-10

High Temperature Blending Chart, Method A
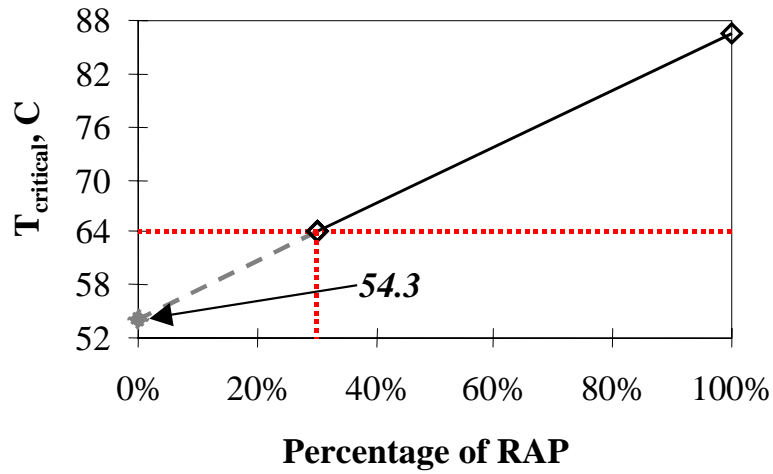
Intermediate Temperature Blending Chart, Method A

Low Temperature Blending Chart, Method A

Estimated Critical Temperatures Needed of Virgin Binder

| Property	Critical Temperature, C	
DSR G*/sinδ	High	**54.3**
DSR G*/sinδ	High	53.4
DSR G*sinδ	Intermed.	**22.6**
BBR S	Low	-15.2
BBR m-value	Low	**-16.4**
PG	Actual	PG 54-26
	MP1	PG 58-28

Use PG58-28
for the virgin binder

Example of Method B - Blending with Known Virgin Binder

- Desired Final Binder Grade = PG64-22 or better
- Virgin binder grade is PG58-28
- Recovered RAP is a PG82-10
- Critical temperatures of virgin and RAP binders are determined.

Virgin and RAP Binder Critical Temperatures

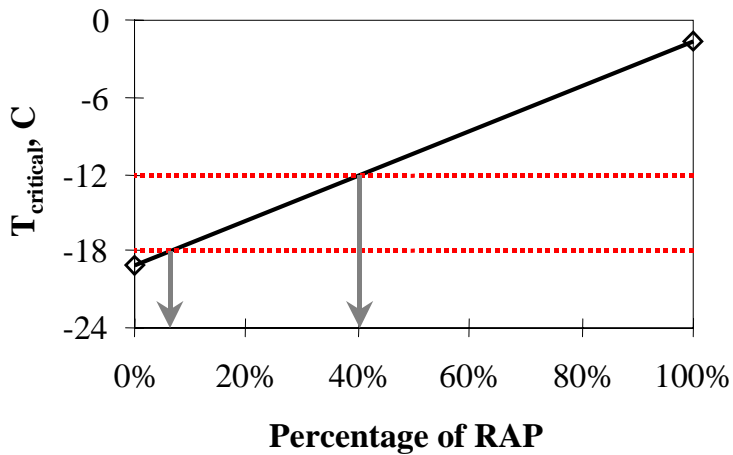| Property		Critical Temperature, C	
	Temp. Range	Virgin Binder	RAP Binder
DSR G*/sin δ	High	**60.5**	**86.6**
DSR G*/sin δ	High	61.0	88.7
DSR G*sin δ	Intermediate	**14.2**	**30.5**
BBR S	Low	-22.2	-4.5
BBR m-value	Low	**-19.0**	**-1.7**
PG	Actual	PG 60-29	PG 86-11
	MP1	PG 58-28	PG 82-10

High Temperature Blending Chart, Method B
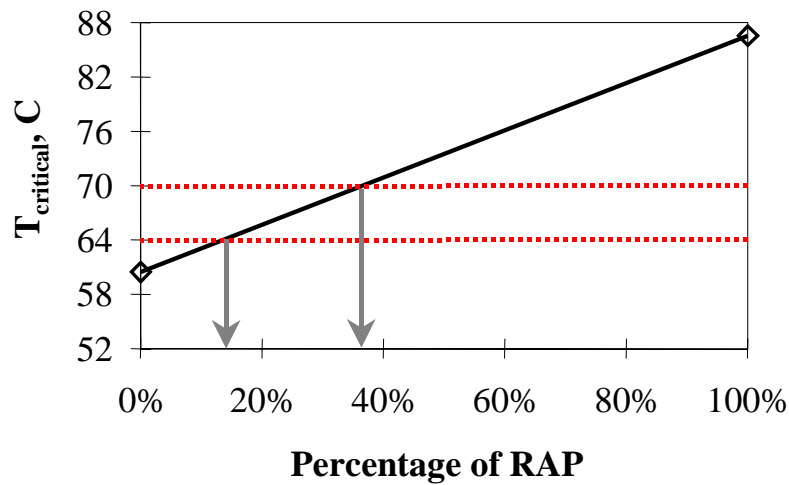
Intermediate Temperature Blending Chart, Method B
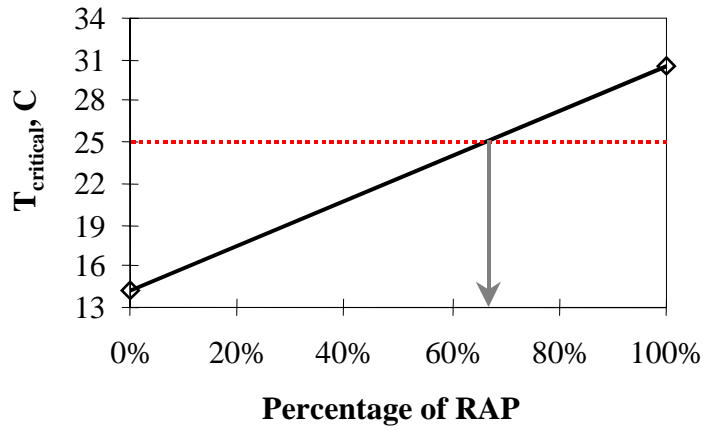
Low Temperature Blending Chart, Method B

Estimated RAP Content to Achieve Final Blended Grade

Property	Temperature	Percentage of RAP to Achieve:	
		PG 64-22	PG 70-28
DSR G*/sinδ	High	**13.4%**	**36.4%**
DSR G*/sinδ	High	10.8%	32.5%
DSR G*sinδ	Intermediate	**66.3%**	---
BBR S	Low	57.6%	23.7%
BBR m-value	Low	**40.5%**	**5.8%**

RAP Content

- To achieve PG64-22, use between 14 and 36% RAP.

Summary

- Include RAP aggregate in gradation and determination of consensus properties of trial and final blends.

- Evaluate RAP binder properties if RAP is very hard or high percentages are used.

- Adjust virgin binder grade by decreasing grade or constructing blending charts, depending on RAP stiffness and content.

APPENDIX G
PROPOSED PROCEDURE FOR DETERMINING THE ASPHALT BINDER GRADE
RECOVERED FROM HMA

Although not a direct product of the research under NCHRP 9-12, the panel asked the research

team to consider a possible extension of this work to suggest a procedure for verifying the grade of an

asphalt binder in a sample of HMA. The following produce is, then, a suggestion based on previous

research under SHRP, some of the work under NCHRP 9-12, and experience with HMA. This procedure

is not supported by any data generated during NCHRP 9-12.

Proposed Procedure for Determining the Asphalt Binder Grade Recovered from HMA

R. Michael Anderson, Asphalt Institute

This procedure outlines the steps necessary to determine the performance grade of an asphalt binder recovered from a sample of hot mix asphalt (HMA) containing RAP. This procedure may be used to determine if the recovered binder grade matches design expectations. To account for testing variability and validate the binder grade, it is recommended that two recoveries and associated binder testing be performed on each sample.

1. Sample the HMA in accordance with appropriate sampling procedures. Obtain a sample size of approximately 8,000 grams.

2. Discharge the sample onto a splitting board and split into quarters.

3. If performing centrifuge extraction (ASTM D2172) followed by Rotavapor recovery (ASTM D5404), select opposite quarters for testing.

4. If performing the modified SHRP extraction-recovery procedure (AASHTO TP2), select opposite quarters and combine. Quarter the combined sample, and select opposite quarters for testing.

> Note: Research conducted during SHRP and validated during the NCHRP 9-12 study indicated that sample sizes substantially larger than 1000 grams may alter the recovered asphalt binder properties. Therefore, a sample size of 900 – 1100 grams is recommended when conducting testing using AASHTO TP2.

5. Perform the selected extraction-recovery procedure and recover the asphalt binder from one of the sample quarters.

6. Perform testing to grade the asphalt binder in accordance with AASHTO MP1 with the following exceptions: (a) rotational viscosity, flash point, and original DSR testing is not required; and (b) rolling thin film oven (RTFO) aging is not required – the recovered asphalt binder sample should be treated as if it already had been subjected to RTFO-aging.

> Note: RTFO aging is intended to simulate the oxidation and volatilization of an asphalt binder during HMA production and construction. Some asphalt technologists also consider that the RTFO simulates 1-2 years of in-place aging. Some asphalt technologists also theorize that the aging process that occurs in a drum-mix plant is different than the process in a batch plant. As a result, the RTFO procedure may not adequately simulate the actual post-production, recovered stiffness of an asphalt binder.
>
> It is recommended that agencies wishing to verify the recovered asphalt binder grade of a mixture containing RAP first experiment with the determination of the asphalt binder grade of a conventional (non-RAP) mixture to determine the expected change in stiffness caused during the mixture production.
>
> For example, an asphalt binder sample obtained from the Contractor's tanks indicates an original stiffness of 1.22 kPa and an RTFO stiffness of 2.44 kPa at 64ºC. After recovery from a mixture sample, the asphalt binder stiffness at 64ºC (no RTFO aging) was determined to be 2.10 kPa (86% of the RTFO data). Based on this information, the agency may decide to adjust the specification limits for recovered asphalt binder from a minimum of 2.20 kPa to a minimum of 1.90 kPa (86% of the specification limit).

7. PAV aging should be performed prior to performing intermediate and/or low temperature binder tests.

8. To validate the recovery procedure and test results, it is recommended (although not required) to repeat Steps 5-7.

9. Report the results from the two individual tests in addition to the average test values.