Washington State Department of Transportation

WSDOT SOP 732[1]

Volumetric Design for Hot-Mix Asphalt (HMA)

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 (V_a), voids in the mineral aggregate (VMA), and voids filled with asphalt (VFA).

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

M 320	Performance-Graded Asphalt Binder
M 323	Superpave Volumetric Mix Design
R 30	Mixture Conditioning of Hot-Mix Asphalt (HMA)
R 35	Superpave Volumetric Design for Hot-Mix Asphalt (HMA)
R 90	Sampling of Aggregates
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 84	Specific Gravity and Absorption of Fine Aggregate
T 85	Specific Gravity and Absorption of Coarse Aggregate
T 100	Specific Gravity of Soils
T 166	Bulk Specific Gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens
T 209	Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt Paving Mixtures
T 228	Specific Gravity of Semi-Solid Bituminous Materials

[1]This Standard Operating procedure is based on AASHTO M 323-22

R 76	Reducing Samples of Aggregate to Testing Size
T 275	Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Paraffin-Coated Specimens
T 283	Resistance of Compacted Asphalt Mixture to Moisture-Induced Damage
T 304	Uncompacted Void Content of Fine Aggregate
T 312	Preparing and Determining the Density of the Hot-Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

2.2 Asphalt Institute

2.3 ASTM Standards

2.4 WSDOT Standards

Construction Manual M 41-01

Standard Specifications M 41-10

Materials Manual M 46-01

SOP 731	Method for Determining Volumetric Properties of Hot-Mix Asphalt (HMA)
R 90	WSDOT Errata to FOP for AASHTO Sampling Aggregate Products
T 27/11	WSDOT FOP for WAQTC/AASHTO for Sieve Analysis of Fine and Coarse Aggregates
T 113	Method of Test for Determination of Degradation Value
T 166	WSDOT FOP for AASHTO for Bulk Specific Gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens
T 176	WSDOT FOP for AASHTO for Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
T 209	WSDOT FOP for AASHTO for Method of Test for Maximum Specific Gravity of Hot Mix Asphalt Paving Mixtures “Rice Density”
R 76	WSDOT FOP for AASHTO for Reducing Samples of Aggregates to Testing Size
T 304	WSDOT Test Method for AASHTO T 304 Uncompacted Void Content of Fine Aggregate
T 312	WSDOT FOP for AASHTO for Preparing and Determining the Density of Hot-Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor
T 335	WSDOT FOP for AASHTO T 335 Determining the Percentage of Fracture in Coarse Aggregate
T 324	WSDOT FOP for AASHTO T324 Hamburg Wheel-Track Testing of Compacted Asphalt Mixtures

2.5 WAQTC Standards

TM 14	Laboratory Prepared Asphalt Mixture Specimens

3. Terminology

3.1 **HMA** – Hot-mix asphalt.

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

3.2.1 Discussion – Design ESALs are the anticipated project traffic level expected on the design lane over a 15-year period. For pavements designed for more or less than 15 years, determine the design ESALs for 15 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 *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 (V_a), and the effective binder content(P_{be}), 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 voids in the mineral aggregate (VMA) filled with binder (the effective binder volume divided by the VMA).

3.9 **Dust/Asphalt Ratio (P_{200}/P_{be})** – By mass, ratio between percent passing the No. 200 (0.075 mm) sieve (P_{200}) and the effective binder content (P_{be}).

3.10 **Nominal maximum aggregate size** – For aggregate, the nominal maximum size, (NMS) is the largest standard sieve opening listed in the applicable specification, upon which any material is permitted to be retained. For concrete aggregate, NMS is the smallest standard sieve opening through which the entire amount of aggregate is permitted to pass.

WSDOT Note 1: For an aggregate specification having a generally unrestrictive gradation (i.e., wide range of permissible upper sizes), where the source consistently fully passes a screen substantially smaller than the maximum specified size, the nominal maximum size, for the purpose of defining sampling and test specimen size requirements may be adjusted to the screen, found by experience to retain no more than 5% of the materials.

3.11 **Maximum aggregate size** – One size larger than the nominal maximum aggregate size (Note 2).

Note 2: The definitions given in sections 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 materials containing asphalt binder and aggregate.

3.13 **$N_{initial}$, N_{design}, $N_{maximum}$** – the number of gyrations defined in WSDOT *Standard Specification* 9-03.8(2).

3.14 **Effective Asphalt Content (P_{be})** – The total asphalt content of a paving mixture minus the portion of asphalt that is lost by absorption into the aggregate particles (Note 1).

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 theoretical maximum specific gravity (G_{mm}) of the RAP mixture and using an assumed asphalt absorption for the RAP aggregate to back-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** – It is recommended at least three trial aggregate blend 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 WSDOT FOP for AASHTO T 312. 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 Section 9-03.8(2) of the *Standard Specifications for Road, Bridge, and Municipal Construction* (*Standard Specifications*) for V_a, VMA, VFA, Dust/Asphalt Ratio at N_{design}, and relative density at N_{intial}.

Note 4: Previous Superpave mix design experience with specific aggregate blends may eliminate the need for three trial blends.

4.3 **Design Binder Content Selection** – Replicate specimens are compacted in accordance with WSDOT FOP for AASHTO T 312 at the estimated design binder content and at the estimated design binder content ± 0.5%. The design binder content is selected on the basis of satisfactory conformance with the requirements of Section 9-03.8(2) of the *Standard Specifications* for V_a, VMA, VFA, and Dust/Asphalt Ratio (P_{200}/P_{be}) at N_{des}, and the relative density at N_{ini} and N_{max}. For WSDOT projects, the design binder content selection is determined by the Contractor and is verified by the WSDOT.

4.4 **Evaluating Moisture Susceptibility –** The moisture susceptibility of the design aggregate structure is evaluated at the design binder content: compacted to 7.0 ± 1.0% air voids in accordance with WSDOT FOP for AASHTO T 312, and evaluated for stripping inflection point according to WSDOT FOP for AASHTO T324 Hamburg Wheel-Track Testing of Compacted Asphalt Mixtures. The design shall meet the stripping inflection point requirement of WSDOT Standard Specification 9-03.8(2). The WSDOT State Materials Laboratory will evaluate the HMA for moisture susceptibility.

5. Significance and Use

5.1 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 The asphalt binder grade will be indicated in WSDOT Contract Plans.

6.2 Determine the specific gravity of the binder according to T 228.

6.3 Obtain samples of aggregates proposed to be used for the project from the aggregate stockpiles in accordance with WSDOT Errata to FOP for AASHTO R 90.

Note 5: Each stockpile usually contains a given size of an aggregate fraction. Most projects employ three to five stockpiles to generate a combined gradation conforming to the job-mix formula and Section 9-03.8(6) of the *Standard Specifications*.

6.4 Reduce the samples of aggregate fractions according to WSDOT FOP for AASHTO R 76 to samples of the size specified in WAQTC TM 14 Laboratory Prepared Asphalt Mixture Specimens - Aggregate Preparation.

6.5 Wash and grade each aggregate sample according to WAQTC TM 14 Laboratory Prepared Asphalt Mixture Specimens - Aggregate Preparation.

6.6 Determine the bulk and apparent specific gravity for each coarse and fine aggregate fraction in accordance with T 85 and T 84, respectively, and determine the specific gravity of the mineral filler in accordance with T 100. WSDOT requires specific gravity determinations to be reported to an accuracy of 0.001.

6.7 Blend the aggregate fractions using Equation 1:

$$P = Aa + Bb + Cc, etc. \quad (1)$$

Where:

P	=	Percentage of material passing a given sieve for the combined aggregates *A*, *B*, *C*, *etc*.
A, *B*, *C*, *etc.*	=	Percentage of material passing a given sieve for aggregates *A*, *B*, *C*, *etc*.
a, *b*, *c*, *etc.*	=	proportions of aggregates *A*, *B*, *C*, *etc*. used in the combination, and where the total = 1.00.

6.8 Prepare a minimum of three trial aggregate blend gradations; plot the gradation of each trial blend on a 0.45-power gradation analysis chart, and confirm that each trial blend meets the Aggregate Gradation Control Points in Section 9-03.8(6) of the *Standard Specifications* 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 No. 4 or No. 8 (4.75- or 2.36 mm) sieve, and the No. 200 (0.075 mm) sieve. For WSDOT projects, gradation shall be determined by the following sieves as defined in table W1T An example of three acceptable trial blends in the form of a gradation plot is given in Figure 1.

Table W1T

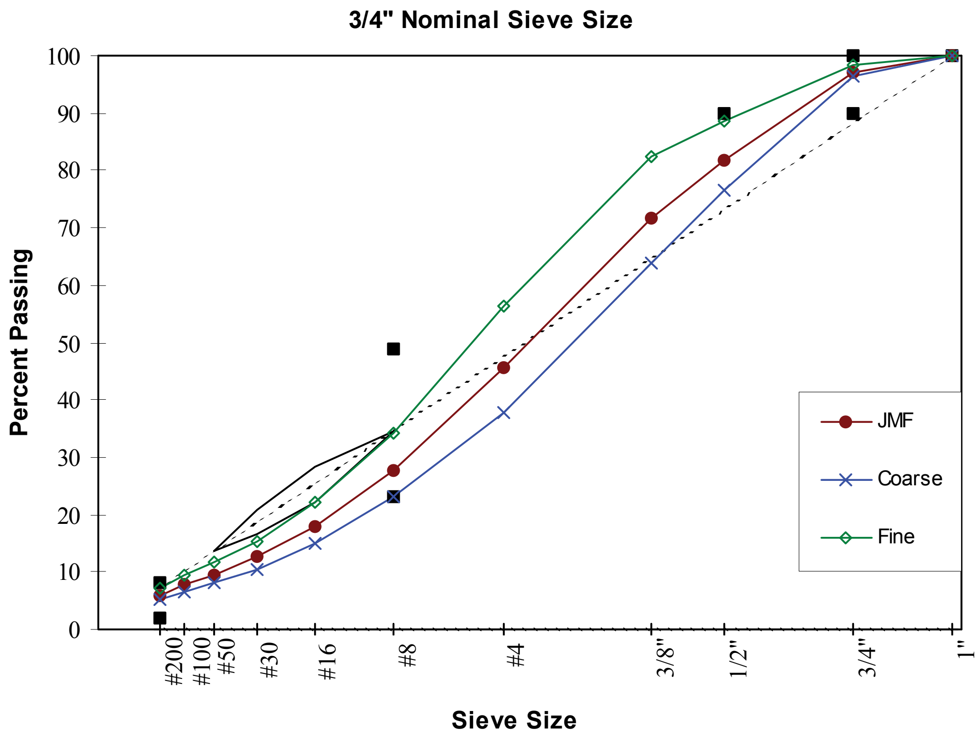
Sieves Required for Gradation Determination				
Sieve Size	**⅜ in**	**½ in**	**¾ in**	**1 in**
1½”				X
1”			X	X
¾”		X	X	X
½”	X	X	X	X
⅜”	X	X	X	X
No. 4	X	X	X	X
No. 8	X	X	X	X
No. 16	X	X	X	X
No. 30	X	X	X	X
No. 50	X	X	X	X
No. 100	X	X	X	X
No. 200	X	X	X	X

X = indicates sieve is required for gradation determination

6.9 Obtain a test specimen from each of the trial blends according to WSDOT FOP for AASHTO R 76, and conduct the quality tests specified in Section 9-03.8(2) subsections 1, 2, 3, and 4 of the *Standard Specifications* to confirm that the aggregate in the trial blends meets the minimum quality requirements specified in Section 9-03.8(2) of the *Standard Specifications*.

Note 6: 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.

Figure 1 Evaluation of the Gradations of Three Trial Blends (Example)



7. Determining an Initial Trial Binder Content for Each Trial Aggregate Gradation

7.1 Designers can either use their experience with the materials or the procedure given in Appendix A1 to determine an initial trial binder content for each trial aggregate blend gradation.

Note 7: 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 8) at the initial trial binder content for each of the chosen trial aggregate trial blend gradations. From Table 1, determine the number of gyrations based on the design ESALs for the project. On WSDOT projects the ESAL level will be indicated in the Contract Special Provisions.

Note 8: At least two replicate specimens are required, but three or more may be prepared if desired. Generally, 4500 to 4700 g of aggregate is sufficient for each compacted specimen with a height of 110 to 120 mm for aggregates with combined bulk specific gravities of 2.550 to 2.700, respectively.

8.2 Condition the mixtures according to R 30, and compact the specimens to N_{design} gyrations in accordance with WSDOT FOP for AASHTO T 312. 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 WSDOT FOP for AASHTO T 166 or T 275 as appropriate. The bulk specific gravity results of the replicate specimens shall not differ by more than 0.020.

Table 1 Superpave Gyratory Compaction Effort

Design ESALs[a] (million)	Compaction Parameters			Typical Roadway Application[b]
	$N_{initial}$	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, U.S. highways, and some rural Interstates.
≥ 30	9	125	205	Applications include the vast majority of the U.S. 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.

[a]The anticipated project traffic level expected on the design lane over a 15-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 15 years.
[b]As defined by *A Policy on Geometric Design of Highways and Streets, 2001*, AASHTO.

8.4 Determine the theoretical maximum specific gravity (G_{mm}) according to WSDOT FOP for AASHTO T 209 of separate samples representing each of these combinations that have been mixed and conditioned to the same extent as the compacted specimens.

Note 11: The maximum specific gravity for each trial mixture shall be based on the average of at least two tests. The maximum specific gravity results of the replicate specimens shall not differ by more than 0.011.

9. Evaluating Compacted Trial Mixtures

9.1 Determine the volumetric requirements for the trial mixtures in accordance with Section 9-03.8(2) of the *Standard Specifications*.

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

$$V_a = 100 \times \left(1 - \left(\frac{G_{mb}}{G_{mm}}\right)\right) \tag{2}$$

$$VMA = 100 - \left(\frac{G_{mb}P_s}{G_{sb}}\right) \tag{3}$$

Where:

G_{mb} = Bulk specific gravity of the extruded specimen
G_{mm} = Theoretical maximum specific gravity of the mixture
P_s = Percent of aggregate in the mixture (100-P_b)
G_{sb} = Bulk specific gravity of the combined aggregate

Note 12: Although the initial trial binder content was estimated for a design air void content of 4.0%, the actual air void content of the compacted specimen is unlikely to be exactly 4.0%. Therefore, the change in binder content needed to obtain a 4.0% 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%.

9.3 Estimate the volumetric properties at 4.0 percent air voids for each compacted specimen. On WSDOT projects, the gyration level will be specified in the Contract Provisions.

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% using Equation 4:

$$\Delta V_a = 4.0 - V_a \tag{4}$$

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

$$\Delta P_b = -0.4\ (\Delta V_a) \tag{5}$$

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 trial aggregate blend gradation, using Equations 6 or 7.

$$\Delta VMA = 0.2(\Delta V_a) \text{ if } V_a > 4.0 \tag{6}$$

$$\Delta VMA = -0.1(\Delta V_a)\ if\ V_a < 4.0 \tag{7}$$

Note 13: 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% air voids using Equation 8:

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

Where:

VMA_{design} = VMA estimated at a design air void content of 4.0%
VMA_{trial} = 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}:

$$\%G_{mm_{initial}} = 100 \times \left(\frac{G_{mb} h_d}{G_{mm} h_i}\right) - \Delta V_a \quad (9)$$

Where:

$\%G_{mm\ initial}$ = 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*
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 (P_{be}) and calculate the Dust/Asphalt Ratio (P_{200}/P_{be}) for each trial blend using Equations 10 and 11:

$$P_{be_{est}} = -(P_s \times G_b)\frac{(G_{se} - G_{sb})}{(G_{se} \times G_{sb})} + P_{b_{est}} \quad (10)$$

Where:

$P_{be_{est}}$ = Estimated effective binder content
P_s = Percent of aggregate in the mixture (100-P_b)
G_b = Specific gravity of the binder
G_{se} = Effective specific gravity of the aggregate
G_{sb} = Bulk specific gravity of the combined aggregate
$P_{b_{est}}$ = Estimated binder content

$$\text{Dust/Asphalt Ratio} = \frac{P_{200}}{P_{be}} \quad (11)$$

Where:

P_{200} = Percent passing the No. 200 (0.075 mm) sieve

9.3.7 Compare the estimated volumetric properties from each trial aggregate blend gradation at the adjusted design binder content with the criteria specified in Section 9-03.8(2) of the *Standard Specifications*. Choose the trial aggregate blend gradation that best satisfies the volumetric criteria.

Note 14: Table 2 presents an example of the selection of a design aggregate structure from three trial aggregate blend gradations.

Note 15: Many trial aggregate blend gradations will fail the VMA criterion. Generally, the % criterion will be met if the VMA criterion is satisfied. Section 12.1 gives a procedure for the adjustment of VMA.

Note 16: 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 that 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.

Table 2 Selection of a Design Aggregate Structure (Example)

Volumetric Property	Trial Mixture (¾ Inch Nominal Maximum Aggregate) 15 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	
$\%G_{mm\ initial}$(trial)	88.1	87.8	87.1	
$\%G_{mm\ design}$(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
$\%G_{mm\ initial}$(design)	88.2	89.5	88.4	≤ 89.0

Notes:

1. 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.
2. 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 TV_a = 4.0 percent, and
   (2) obtain adjusted VMA and relative density values at this estimated binder content.
3. The middle portion of this table presents the change in binder content (ΔP_b) and VMA (ΔVMA) that occurs when the target air void content (TV_a) is adjusted to 4.0 percent for each trial aggregate blend gradation.
4. A comparison of the VMA and densities at the estimated design binder content to the criteria in the last column shows that trial aggregate blend gradation No. 1 does not have sufficient VMA (12.9% versus a requirement of ≥ 13.0%). Trial blend No. 2 exceeds the criterion for relative density at $N_{initial}$ gyrations (89.5% versus requirement of ≤ 89.0%). Trial No. 3 meets the requirement for relative density and VMA and, in this example, is selected as the design aggregate structure.

10. Selecting the Design Binder Content

10.1 Prepare replicate mixtures (Note 8) containing the selected design aggregate structure at each of the following three binder contents: (1) the estimated design binder content, $P_{b\ (design)}$; (2) 0.5% below $P_{b\ (design)}$; and (3) 0.5% above $P_{b\ (design)}$.

10.1.1 Use the number of gyrations previously determined in Section 8.1.

10.2 Condition the mixtures according to R 30, and compact the specimens to N_{design} gyrations according to WSDOT FOP for AASHTO T 312. 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 WSDOT FOP for AASHTO T 166 or AASHTO T 275 as appropriate.

10.4 Determine the theoretical maximum specific gravity (G_{mm}) according to WSDOT FOP for AASHTO T 209 of each of the three mixtures using companion samples which have been conditioned to the same extent as the compacted specimens (Note 8).

10.5 Determine the design binder content which produces a target air void content 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: The volumetric properties are determined for each specimen and then averaged for each replicate mixture.

$$VFA = 100 \times \left(\frac{VMA - V_a}{VMA}\right) \tag{12}$$

10.5.2 Calculate the Dust/Asphalt Ratio, using Equation 13.

$$\text{Dust/Asphalt Ration } \frac{P_{200}}{P_{be}} \tag{13}$$

Where:

P_{be} = Effective binder content

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

$$\%G_{mm_{initial}} = 100 \times \left(\frac{G_{mb} h_d}{G_{mm} h_i}\right) \tag{14}$$

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

Note 17: 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 Section 9-03.8(2) of the *Standard Specifications* 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, $\%G_{mm\,x}$, 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 $N_{initial}$. Confirm that satisfies the design requirements in Section 9-03.8(2) of the *Standard Specifications* at the design binder content.

10.7 Prepare replicate (Note 8) specimens composed of the design aggregate structure at the design binder content to confirm that $\%G_{mm\,max}$ satisfies the design requirements in Section 9-03.8(2) of the *Standard Specifications*.

10.7.1 Condition the mixtures according to R-30, and compact the specimens according to WSDOT FOP for AASHTO T312 to the maximum number of gyrations, N_{max}, from Section 9-03.8(2) of the *Standard Specifications.*

10.7.2 Determine the average specimen relative density at N_{max}, $\%G_{mm\,max}$, by using Equation 15, and confirm that satisfies the volumetric requirement in Section 9-03.8(2) of the *Standard Specifications*.

$$\%G_{mm_{max}} = 100 \times \frac{G_{mb}}{G_{mm}} \tag{15}$$

Where:

$\%G_{mm\,max}$ = Relative density at N_{max} gyrations at the design binder content

Figure 2 Sample Volumetric Design Data at N_{des}

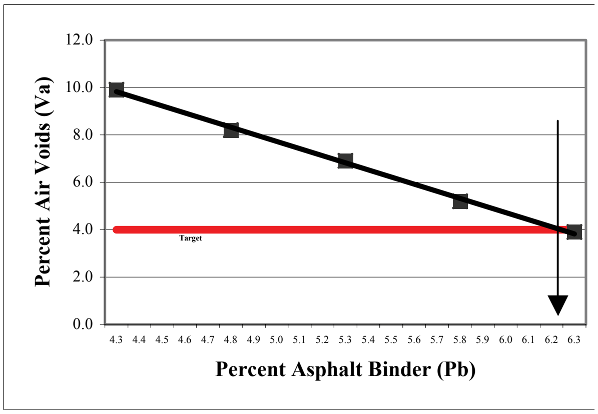
P_b(%)	V_a(%)	VMA (%)	VFA (%)	Maximum Density at N_{design} (G_{mm})	Density at N_{design} lbs/ft^3
4.3	9.9	17.0	41.8	2.660	165.6
4.8	8.2	16.7	50.9	2.636	164.1
5.3	6.9	16.6	58.5	2.617	162.9
5.8	5.2	16.5	68.5	2.585	160.9
6.3	3.9	16.2	76.0	2.574	160.2

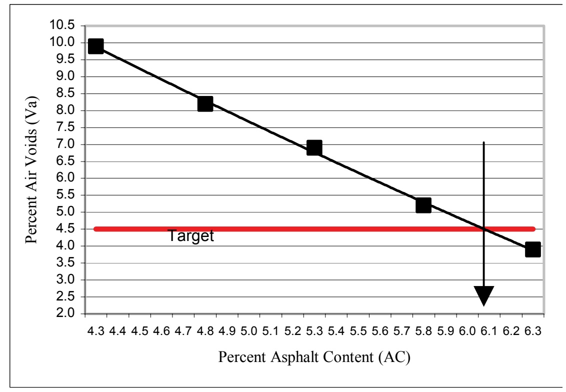
In this example, the estimated design binder content is 4.8 percent; the minimum VMA requirement for the design aggregate structure (¾ in nominal maximum size) is 13.0 percent, and the VFA requirements is 65 to 78 percent.

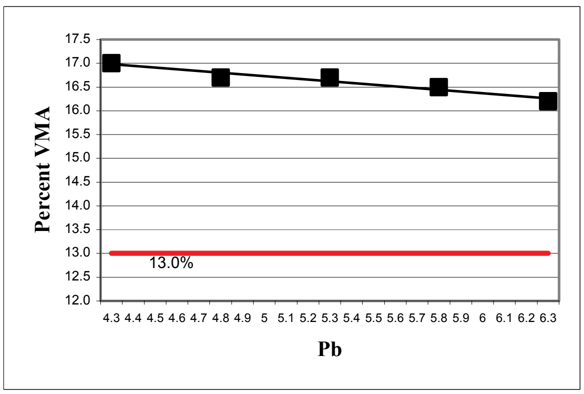
Entering the plot of percent air voids versus percent binder content at 4.0 percent air voids, the design binder content is determined as 6.2 percent.

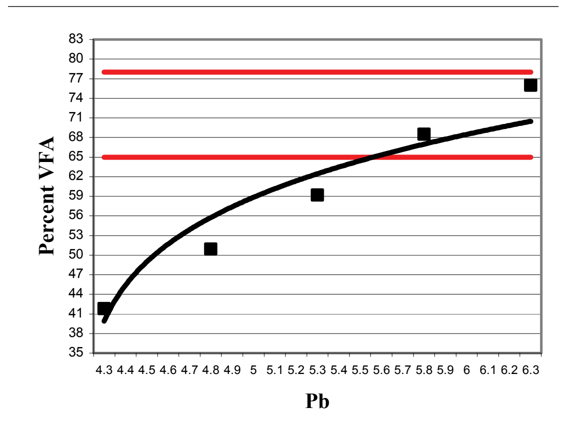
Entering the plots of percent VMA versus percent binder content and percent VFA versus percent binder content at 6.2 percent binder content, the mix meets the VMA and VFA requirement.

Figure 3 Sample Densification Curve









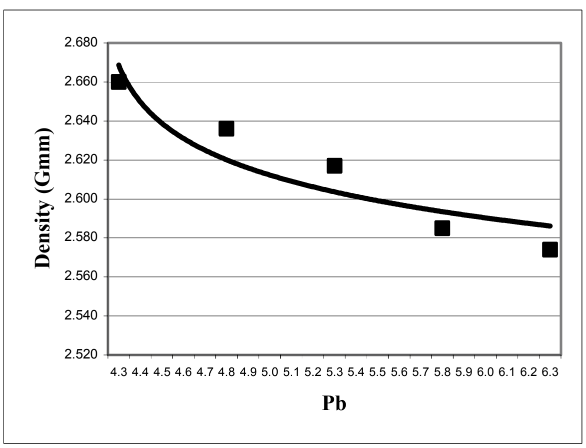
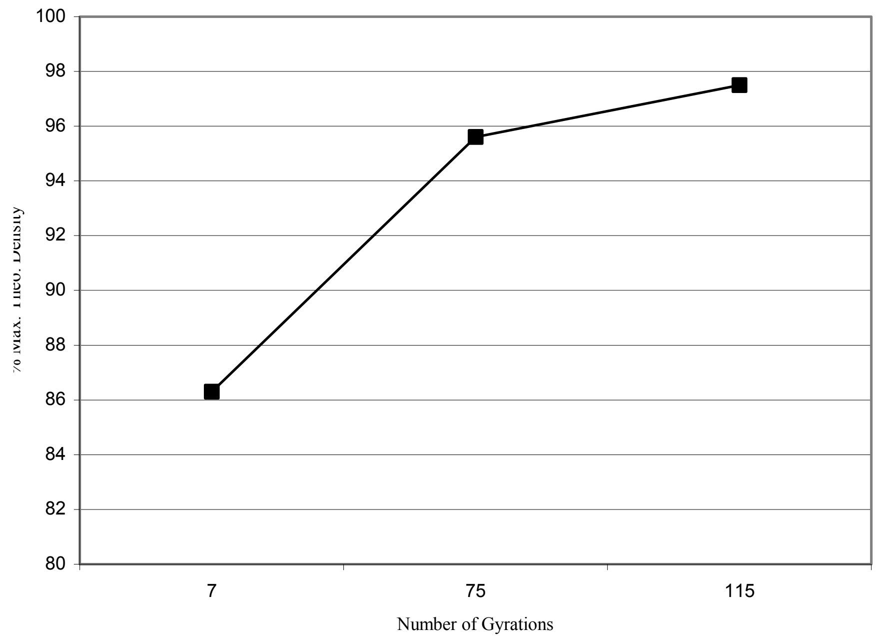


Figure 4



11. Evaluating Moisture Susceptibility

11.1 Prepare two mixture specimens composed of the design aggregate structure at the design binder content. Prepare the specimens according to WAQTC TM 14 Laboratory Prepared Asphalt Mixture Specimens, and compact the specimens to 7.0 ± 1.0% air voids in accordance to WSDOT FOP for AASHTO T 312.

11.2 The WSDOT State Materials Laboratory will evaluate the HMA for moisture susceptibility by determining the stripping inflection point in accordance with WSDOT FOP for AASHTO T324 Hamburg Wheel-Track Testing of Compacted Asphalt Mixtures and meets WSDOT Standard Specification 9-03.8(2).

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 18); (2) reduce the minus No. 200 (0.075 mm) fraction (Note 19); or (3) change the surface texture and/or shape of one or more of the aggregate fractions (Note 20).

Note 18: Changing gradation may not be an option if the trial aggregate blend gradation analysis includes the full spectrum of the gradation control area.

Note 19: Reducing the percent passing the No. 200 (0.075 mm) sieve of the mix will typically increase the VMA. If the percent passing the No. 200 (0.075 mm) sieve is already low, this is not a viable option.

Note 20: 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% 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 No. 200 (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.

13. Report

13.1 The report shall include the identification of the project number, mix class designation, and mix design number.

13.2 The report shall include information on the design aggregate structure including the source of aggregate, and gradation, including the blending ratios.

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_a, and Dust/Asphalt Ratio P_{be}, G_{mm}, G_{mb}, G_{sb} and G_{se} of the aggregate blend, G_{sb} of the fine aggregate, and G_b.

13.5 The report shall contain the results of the moisture susceptibility testing and the required level of anti-strip additive needed.

14. Keywords

14.1 HMA mix design; Superpave; volumetric mix design.

Appendix

A1. Calculating an Initial Trial Binder Content for Each Aggregate Trial Blend

Nonmandatory Information

A1.1 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 Section 6.6 and Equations 16 and 17:

$$G_{sb} = \frac{P_1 + P_2 + \cdots + P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \cdots + \frac{P_n}{G_n}} \tag{16}$$

$$G_{sa} = \frac{P_1 + P_2 + \cdots + P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \cdots + \frac{P_n}{G_n}} \tag{17}$$

Where:

G_{sb} = Bulk specific gravity for the combined aggregate
G_{sa} = Apparent specific gravity for the combined aggregate
P_1, P_2, P_n = Percentages by mass of aggregates 1, 2, n
G_1, G_2, G_n = Bulk specific gravities (Equation 16) or apparent specific gravities (Equation 17) of aggregates 1, 2, *n*.

A1.2 Estimate the effective specific gravity of the combined aggregate in the aggregate trial blend using Equation 18:

$$G_{se} = G_{sb} + 0.8(G_{sa} - G_{sb}) \tag{18}$$

Where:

G_{se} = Effective specific gravity of the combined aggregate
G_{sb} = Bulk specific gravity of the combined aggregate
G_{sa} = Apparent specific gravity of the combined aggregate

Note 21: 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 22: 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.

A1.3 Estimate the volume of binder absorbed into the aggregate, V_{ba}, using Equations 19 and 20:

$$V_{ba} = W_s\left(\frac{1}{G_{sb}} - \frac{1}{G_{se}}\right) \tag{19}$$

Where:

W_s = The mass of aggregate in 1 cm^3 of mix, g, is calculated as

$$W_s = \frac{P_s(1 - V_a)}{\frac{P_b}{G_b} + \frac{P_s}{G_{se}}} \tag{20}$$

and Where:

P_b = Percent of binder, in decimal equivalent, assumed to be 0.05
P_s = Percent of aggregate in mixture, in decimal equivalent, assumed to be 0.95
G_b = Specific gravity of the binder
V_a = Volume of air voids, assumed to be 0.04 cm^3 in 1 cm^3 of mix

Note 23: 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%.

A1.4 Estimate the volume of effective binder using Equation 21:

$$V_{be} = 0.176 - (0.0675 \log\ (S_n)) \tag{21}$$

Where:

V_{be} = Volume of effective binder, cm^3
S_n = Nominal maximum sieve size of the largest aggregate in the aggregate trial blend, mm.

Note 24: 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 – V_a = VMA – 4.0; and (2) the relationship between VMA and the nominal maximum sieve size of the aggregate in MP 2. For WSDOT projects, see contract provisions.

A1.5 Calculate the estimated initial trial binder (P_{bi}) content for the aggregate trial blend gradation using Equation 22:

$$P_{bi} = 100 \times \left(\frac{G_b(V_{be} + V_{ba})}{\left(G_b(V_{be} + V_{ba})\right) + W_s}\right) \tag{22}$$

Where:

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