
Standard Practice for Superpave Volumetric Design for Asphalt Mixtures

AASHTO Designation: R 35-22¹

Technically Revised: 2022

Editorially Revised: 2022

**Technical Subcommittee: 2d, Proportioning
of Asphalt–Aggregate Mixtures**



**American Association of State Highway and Transportation Officials
555 12th Street NW, Suite 1000
Washington, DC 20004**

Standard Practice for

Superpave Volumetric Design for Asphalt Mixtures

AASHTO Designation: R 35-22¹

AASHTO

Technically Revised: 2022

Editorially Revised: 2022

Technical Subcommittee: 2d, Proportioning of Asphalt–Aggregate Mixtures

1. SCOPE

- 1.1. This standard practice for mix design evaluation uses aggregate and mixture properties to produce an asphalt mixture job mix formula. The mix design is based on the volumetric properties of the asphalt mixture in terms of the air voids, voids in the mineral aggregate (VMA), and voids filled with asphalt (VFA). This standard practice may be used to evaluate Superpave mixtures based on 4.0 percent air void content or Superpave5 mixtures based on 5.0 percent air void content. It is important to note that Superpave and Superpave5 methodologies are similar but not the same. The designer must choose Superpave or Superpave5 and follow the practice as appropriate. Requirements for Superpave5 that are significantly different from Superpave are included in Annex A.
- 1.2. This standard practice may also be used to provide a preliminary selection of mix parameters as a starting point for mix analysis and performance prediction analyses.
- 1.3. Special mixture design considerations and practices to be used in conjunction with this standard practice for the volumetric design of Warm Mix Asphalt (WMA) are given in Appendix X2.
- 1.4. *This standard practice may involve hazardous materials, operations, and equipment. This standard practice does not purport to address all of the safety concerns, if any, 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
 - < M 339M/M 339, Thermometers Used in the Testing of Construction Materials
 - < R 30, Laboratory Conditioning of Asphalt Mixtures
 - < R 76, Reducing Samples of Aggregate to Testing Size
 - < R 83, Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)
 - < R 90, Sampling Aggregate Products
 - < T 11, Materials Finer Than 75- μ m (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 (G_{mb}) of Compacted Asphalt Mixtures Using Saturated Surface-Dry Specimens
- T 195, Determining Degree of Particle Coating of Asphalt Mixtures
- T 209, Theoretical Maximum Specific Gravity (G_{mm}) and Density of Asphalt Mixtures
- T 228, Specific Gravity of Semi-Solid Asphalt Materials
- T 275, Bulk Specific Gravity (G_{mb}) of Compacted Asphalt Mixtures Using Paraffin-Coated Specimens
- T 283, Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage
- T 312, Preparing and Determining the Density of Asphalt Mixture Specimens by Means of the Superpave Gyrotory Compactor
- T 324, Hamburg Wheel-Track Testing of Compacted Asphalt Mixtures
- T 378, Determining the Dynamic Modulus and Flow Number for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT)
- *A Policy on Geometric Design of Highways and Streets*

2.2. *ASTM Standards:*

- E1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E230/E230M, Standard Specification for Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples

2.3. *International Electrotechnical Commission Standard:*

- IEC 60584-1:2013, Thermocouples - Part 1: EMF Specifications and Tolerances

2.4. *Other References:*

- LTPP Seasonal Asphalt Concrete Pavement Temperature Models, LTPPBind, Available online at <https://infopave.fhwa.dot.gov/Tools/LTPPBindOnline>.

Note 1—The different generations of the LTPPBind program use different algorithms and weather databases for determining the PG high temperature for a location. The choice of which LTPPBind version to use is up to the specifier.

- NCHRP. *National Cooperative Highway Research Report 567: Volumetric Requirements for Superpave Mix Design*. National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 2006.

3. TERMINOLOGY

- 3.1. *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).
- 3.2. *air voids (V_a)*—the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture.
- 3.3. *binder content (P_b)*—the percent by mass of binder in the total mixture, including binder and aggregate.

- 3.4. *design air void content*—the required percent air voids (V_a) at N_{design} gyrations, or 100 percent minus the required percent G_{mm} (relative density) at N_{design} gyrations, from M 323. The design air void content is 4.0 percent for Superpave mixtures and 5.0 percent for Superpave5 mixtures.
- 3.5. *design ESALs*—design equivalent (80 kN) single-axle loads.
- 3.5.1. *discussion*—design ESALs are the anticipated project traffic level expected on the design lane over a 20-year period. For pavements designed for more or less than 20 years, determine the design ESALs for 20 years when using this standard practice.
- 3.6. *dust-to-binder ratio* ($P_{0.075}/P_{be}$)—by mass, the ratio between the percent passing the 75- μ m (No. 200) sieve ($P_{0.075}$) and the effective binder content (P_{be}).
- 3.7. *effective binder volume* (V_{be})—the volume of binder that is not absorbed into the aggregate.
- 3.8. *HMA*—hot mix asphalt.
- 3.9. *maximum aggregate size*—one size larger than the nominal maximum aggregate size (Note 2).
Note 2—The definitions given in Sections 3.9 and 3.10 apply to Superpave mixes only and differ from the definitions published in other AASHTO standards.
- 3.10. *nominal maximum aggregate size*—one size larger than the first sieve that retains more than 10 percent aggregate (Note 2).
- 3.11. *primary control sieve (PCS)*—the sieve defining the break point between fine and coarse-graded mixtures for each nominal maximum aggregate size.
- 3.12. *reclaimed asphalt pavement (RAP)*—removed and/or processed pavement materials containing asphalt binder and aggregate.
- 3.13. *reclaimed asphalt pavement binder ratio (RAPBR)*—The ratio of the RAP binder in the mixture divided by the mixture's total binder content.
- 3.14. *voids filled with asphalt (VFA)*—the percentage of the VMA filled with binder (the effective binder volume divided by the VMA).
- 3.15. *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.
- 3.16. *WMA*—warm mix asphalt.

4. SUMMARY OF THE PRACTICE

- 4.1. *Materials Selection*—Binder, 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 local aggregates.

- 4.2. *Design Aggregate Structure*—It is recommended that 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 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 M 323 for V_a , VMA, VFA, dust-to-binder ratio at N_{design} , and relative density at N_{initial} .

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 T 312 at the estimated design binder content and at the estimated design binder content ± 0.5 percent and $+1.0$ percent. The design binder content is selected on the basis of satisfactory conformance with the requirements of M 323 for V_a , VMA, VFA, and dust-to-binder ratio at N_{design} , and the relative density at N_{initial} and N_{max} .

- 4.4. *Evaluating Moisture Susceptibility*—Evaluate the moisture susceptibility of the design aggregate structure at the design binder content. Oven-condition the mixture according to T 283 Section 6. Compact specimens to 7.0 ± 0.5 percent air voids according to T 312. Group, moisture-condition, test, and evaluate specimens according to T 283. The design shall meet the tensile strength ratio requirement of M 323.

5. SIGNIFICANCE AND USE

- 5.1. The procedure described in this standard practice is used to produce asphalt mixtures that satisfy Superpave asphalt volumetric mix design requirements. At an agency's discretion, this standard practice may be used to produce asphalt mixtures that satisfy Superpave5 asphalt volumetric mix design requirements. Unless noted, all sections apply to Superpave and Superpave5. Requirements specific to Superpave5 are contained in Annex A.

6. PREPARING AGGREGATE TRIAL BLEND GRADATIONS

- 6.1. Select a binder in accordance with the requirements of M 323 and M 320.
- 6.2. Determine the specific gravity of the binder according to T 228.
- 6.3. Obtain samples of aggregates and RAP proposed to be used for the project from the aggregate and RAP stockpiles in accordance with 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 M 323.
- 6.4. Reduce the samples of aggregate fractions according to R 76 to samples of the size specified in T 27.
- 6.5. When RAP is used, dry the RAP samples in an oven at 110°C until constant mass. Avoid exposing RAP to oven conditioning for extended periods of time to minimize further aging of the RAP binder. Determine the binder content of the RAP using T 308 or T 164. Retain the RAP aggregate following ignition or extraction testing for gradation analyses, specific gravity determinations, and aggregate consensus potency tests.

6.6. Wash and grade each aggregate sample according to T 11 and T 27 for the purpose of materials characterization of the aggregates.

6.7. 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.

6.8. Calculate the combined aggregate gradation using Equation 1:

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

where:

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

$A, B, C, \text{ etc.}$ = percentage of material passing a given sieve for aggregates A, B, C, etc.; and

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

6.9. 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 M 323 gradation controls (see Table 4 of M 323). 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 primary control sieve (PCS) from M 323, 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. If RAP is used, adjust the mass of the RAP to account for the RAP binder.

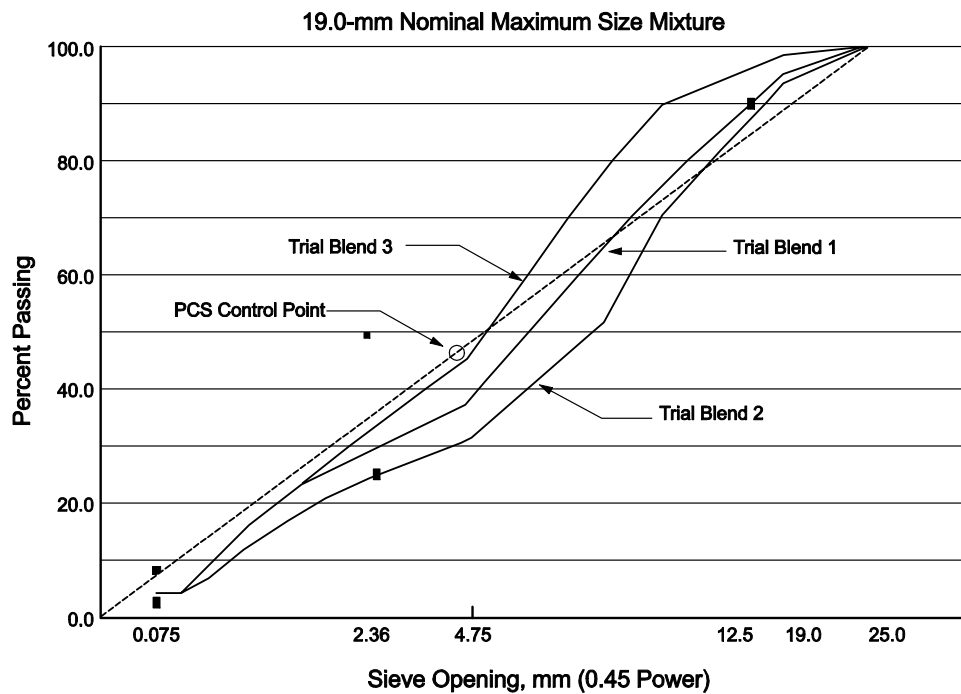


Figure 1—Evaluation of the Gradations of Three Trial Blends (Example)

6.10. Obtain a test specimen from each of the trial blends according to R 76, including RAP aggregate if used, and conduct the quality tests specified in Section 6 of M 323 to confirm that the aggregate in the trial blends meets the minimum quality requirements specified in M 323.

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.

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 X1 to determine an initial trial binder content for each trial aggregate blend gradation.
- Note 7**—When using RAP, the initial trial binder content should be reduced by an amount equal to that provided by the RAP.

8. COMPACTING SPECIMENS OF EACH TRIAL GRADATION

- 8.1. For Superpave mix designs, 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.
- 8.2. For Superpave5 mix designs, prepare replicate mixtures according to Annex A.
- 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 2.55 to 2.70, respectively.
- 8.3. Condition the mixtures according to R 30 and compact the specimens to N_{design} gyrations in accordance with T 312. Record the specimen height to the nearest 0.1 mm after each revolution.
- 8.4. Determine the bulk specific gravity (G_{mb}) of each of the compacted specimens in accordance with T 166 or T 275 as appropriate.

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 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.

^b As defined by A Policy on Geometric Design of Highways and Streets, AASHTO.

Note 9—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 percent of a construction lift is within 100 mm of the surface, the lift may be considered to be below 100 mm for mixture design purposes.

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

- 8.5. Determine the theoretical maximum specific gravity (G_{mm}) according to 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.

9. EVALUATING COMPACTED TRIAL MIXTURES

- 9.1. Determine the volumetric requirements for the trial mixtures in accordance with M 323.

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

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

$$\text{VMA} = 100 - \frac{G_{mb} P_s}{G_{sb}} \quad (3)$$

where:

G_{mb} = bulk specific gravity of the extruded specimen;

G_{mm} = theoretical maximum specific gravity of the mixture;

P_s = aggregate content, percent by mass of total mixture; and

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

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

- 9.3. Estimate the volumetric properties at the design 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 percent air voids using Equation 4:

$$\Delta V_a = \text{design \% air void} \quad (4)$$

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 the design percent using Equation 5:

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

- 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 trial aggregate blend gradation, using Equation 6 or 7.

$$\Delta VMA = 0.2(\Delta V_a) \quad \text{if } V_a > \text{design \% air void} \quad (6)$$

$$\Delta VMA = -0.1(\Delta V_a) \quad \text{if } V_a < \text{design \% air void} \quad (7)$$

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 the design percent air voids using Equation 8:

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

where:

VMA_{design} = VMA estimated at the design air void content; and

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 the design percent at N_{design} :

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

where:

$\%G_{mm_{\text{initial}}}$ = 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. Calculate the effective specific gravity of the aggregate (G_{se}), the estimated percent of effective binder ($P_{be_{\text{est}}}$), and the estimated dust-to-binder ratio ($P_{0.075}/P_{be}$) for each trial blend using Equations 10, 11, and 12:

$$G_{se} = \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}} \quad (10)$$

$$P_{be_{\text{est}}} = -\left(P_s \times G_b\right) \left[\frac{(G_{se} - G_{sb})}{(G_{se} \times G_{sb})} \right] + P_{be_{\text{est}}} \quad (11)$$

where:

$P_{be_{\text{est}}}$ = estimated effective binder content,

P_s = aggregate content, percent by mass of total mixture,

G_b = specific gravity of the binder,

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

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

$P_{be_{\text{est}}}$ = estimated binder content at 4 percent air voids.

$$P_{0.075} / P_{be} = \frac{P_{0.075}}{P_{be_{est}}} \quad (12)$$

where:

$P_{0.075}$ = percent passing the 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 M 323. 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 for a Superpave (4.0 percent air voids) mix design.

Note 15—Many trial aggregate blend gradations will fail the VMA criterion. Generally, the $\%G_{mm_{initial}}$ 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 that 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 for a Superpave Mix Design (Example)

Trial Mixture (19.0-mm Nominal Maximum Aggregate) 20-Year Project Design ESALs = 5 million				
Volumetric Property	1	2	3	Criteria
	At the Initial Trial Binder Content			
P_b (trial)	4.4	4.4	4.4	
$\%G_{mm_{initial}}$ (trial)	88.3	88.0	87.3	
$\%G_{mm_{design}}$ (trial)	95.6	94.9	94.5	
V_a at N_{design}	4.4	5.1	5.5	4.0
VMA_{trial}	13.0	13.6	14.1	
Adjustments to Reach Design Binder Content ($V_a = 4.0\%$ at N_{design})				
ΔV_a	−0.4	−1.1	−1.5	
ΔP_b	0.2	0.4	0.6	
ΔVMA	−0.1	−0.2	−0.3	
At the Estimated Design Binder Content ($V_a = 4.0\%$ at N_{design})				
Estimated P_b (design)	4.6	4.8	5.0	
VMA (design)	12.9	13.4	13.8	≥13.0
$\%G_{mm_{initial}}$ (design)	88.7	89.1	88.5	≤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 $V_a = 4.0$ 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 air void content (V_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 percent versus a requirement of ≥ 13.0 percent). Trial blend No. 2 exceeds the criterion for relative density at $N_{initial}$ gyrations (89.1 percent versus a requirement of ≤ 89.0 percent). Trial blend No. 3 meets the requirement for relative density and VMA and, in this example, is selected as the design aggregate structure.