

Standard Practice for Superpave Volumetric Design for Hot-Mix Asphalt (HMA)

AASHTO Designation: PP28-01^{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 concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 AASHTO Standards:

- 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 a percent of the bulk volume of the compacted paving

¹ This standard is based on SHRP Product M001.

² Approved in December 1995, this provisional standard was first published in June 1996. The 2001 publication includes major changes resulting from the findings of NCHRP 9-12 project.

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 - It is recommended at least three trial aggregate blended 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 ± 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 7.0 ± 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 Trial Aggregate 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 4 - 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:

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

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 recommended 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 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 5 - The designer has an option of performing the quality tests on each stockpile instead of the trial aggregate blend gradations. 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 Blend 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 trial aggregate blend gradation.

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 Aggregate Blend Gradation

8.1 Prepare replicate mixtures (Note 7) at the initial trial binder content for each of the chosen trial aggregate blend gradation. From Table 1, determine the number of gyrations based on the design ESALs for the project.

Note 7 - 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 - 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 8 - 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:

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

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

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 in decimal form; and
- G_{sb} = the bulk specific gravity of the combined aggregate.

Note 9 - 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 blend 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 trial aggregate blend gradation 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:

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

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.

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

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

Note 10 - 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 trial aggregate blend gradation at N_{design} gyrations and 4.0 percent air voids using Equation 8:

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

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} :

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

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 ($P_{be_{est}}$) and calculate the dust-to-binder ratio ($P_{0.075}/P_{be}$) for each trial blend using equations 10 and 11:

where:

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

$P_{be_{est}}$ = 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
 $P_{b_{est}}$ = the estimated binder content.

$$P_{0.075} / P_{be} = \frac{P_{0.075}}{P_{be_{est}}} \quad (11)$$

where:

$P_{0.075}$ = the 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 MP2. Select, as the design aggregate structure, that trial aggregate blend gradation that best satisfies the criteria.

Note 11 - Table 2 presents an example of the selection of a design aggregate structure from

three trial aggregate blend gradation.

Note 12 - Many trial aggregate blend gradation 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 - If the trial aggregate blend gradation 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) containing the selected design aggregate structure at each of the following four binder contents: (1) the estimated design binder content, $P_b(\text{design})$; (2) 0.5 percent below $P_b(\text{design})$; (3) 0.5 percent above $P_b(\text{design})$; and (4) 1.0 percent above $P_b(\text{design})$.

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).

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: