

ALDOT-259-24

OPEN-GRADED ASPHALT CONCRETE FRICTION COURSE DESIGN METHOD

1. Scope

This is the laboratory procedure approved by the Department of Transportation for designing open-graded asphalt concrete friction courses.

2. Referenced Documents

- 2.1. AASHTO R 30, Mixture Conditioning of Hot Mix Asphalt
- 2.2. AASHTO T 11, Materials Finer the 75- μm (No. 200) Sieve in Mineral Aggregates by Washing
- 2.3. AASHTO T 19, Bulk Density ("Unit Weight") and Voids in Aggregate
- 2.4. AASHTO T 27, Sieve Analysis of Fine and Coarse Aggregate
- 2.5. AASHTO T 84, Specific Gravity and Absorption of Fine Aggregate
- 2.6. AASHTO T 85, Specific Gravity and Absorption of Coarse Aggregate
- 2.7. AASHTO T 312, Preparing and Determining the Density of Asphalt Mixture Specimens by Means of the Superpave Gyratory Compactor
- 2.8. AASHTO T 331, Bulk Specific Gravity (G_{mb}) and Density of Compacted Asphalt Mixtures Using Automatic Vacuum Sealing Method
- 2.9. AASHTO TP 108, Abrasion Loss of Asphalt Mixture Specimens
- 2.10. ALDOT - 386 Determination of Draindown Characteristics in Uncompacted Bituminous Mixtures
- 2.11. ALDOT - 361 Resistance of Compacted Hot-Mix asphalt to Moisture Induced Damage

3. Summary of Procedure

- 3.1. Aggregates, asphalt binder, anti-strip additives, and stabilizing additives are selected that meet the requirements of Section 420 of the Specifications. Trial aggregate blends are identified, and then the voids in the coarse aggregate (VCA_{DRC}) is determined for each blend. The blends are then fabricated and compacted with a Superpave Gyratory Compactor (SGC) using a trial asphalt binder content. From the compacted specimens, the voids in the coarse aggregate of the compacted mix is determined (VCA_{MIX}). If VCA_{MIX} is equal to or less than VCA_{DRC} , then the blend has adequate stone-on-stone contact. Once the final blend has been determined, samples are then fabricated and compacted to determine the optimum binder content, based on compacted air voids and Cantabro loss. Following the selection of the optimum binder content, the mixture is tested for moisture susceptibility and draindown.

4. Test Procedure

- 4.1. Determine the gradation of each individual aggregate component in accordance with AASHTO T 27 and T 11.
- 4.2. Determine the bulk specific gravity for the individual coarse aggregate components in accordance with AASHTO T 85 and individual fine aggregate components in accordance with AASHTO T 84.
- 4.3. Determine the bulk density (M) and the percent voids of the coarse aggregate components, each in the dry rodded condition (referred to here as VCA_{DRC}), in accordance with AASHTO T 19.

4.4. Preparing Trial Blends:

- 4.4.1. Selection of Trial Gradations – Select at least three initial trial gradations to fall within the gradation range specified in Section 420 of the Specifications. The trial gradations should typically fall along the coarse and fine limits of the gradation range and one falling in the middle of the range.

Note: Depending on the gradation of the aggregate components, three blends may not be possible or necessary.

- 4.4.2. Determination of Voids in the Coarse Aggregate (VCA) – Based on the blend percentages, determine the void content (VCA_{DRC}) and bulk specific gravity (G_{ca}) of the coarse aggregate fraction.

Note: A calculation example for this step is shown in the appendix.

- 4.4.3. Selection of Trial Binder Content – Use a binder content of 6.5% (by weight of total mixture) to prepare the trial blends.

4.5. Preparing Trial Blend Samples:

- 4.5.1. Preparation of Aggregates – Dry the aggregates to a constant mass, and separate by dry-sieving into the following individual sized fractions:

- Passing 3/4" to retained on 1/2"
- Passing 1/2" to retained on 3/8"
- Passing 3/8" to retained on No. 4
- Passing No. 4 to retained on No. 8
- Passing No. 8

Note: Fractionating the Coarse Aggregate is a critical step that will have a major impact on the repeatability of the results of this procedure.

- 4.5.2. Number of Samples per Trial Blend – Batch a total of four samples for each trial blend. One sample will be used to determine the maximum specific gravity (G_{mm}) according to AASHTO T 209, and the other three samples will be compacted and used to determine the air void content.

- 4.5.3. For each sample, place an appropriate amount of material from each size fraction for the required sample size (approximately 4,000 – 4,200 g). The compacted sample must have a height of 115 ± 5 mm and be compacted in a standard 150 mm diameter gyratory mold.

- 4.5.4. Heat the aggregate and binder to the mixing temperature of 320 – 330°F.

- 4.5.5. Place the heated aggregate batch into the mixing container. Add the required amounts of asphalt binder and stabilizing additive into the container. Mix the aggregate, asphalt binder and stabilizing additives rapidly until thoroughly coated. Slightly longer mixing times may be required due to the increased surface area added by the fiber, compared to mixes without fibers.

Note: Dry-mixing the fibers (if used) into the aggregate before adding the binder has been found to disperse the fibers uniformly throughout the mixture.

Note: Ensure that the asphalt binder contains the required anti-strip additive.

- 4.5.6. Following mixing, short-term age the mixture in accordance with AASHTO R30, at a temperature of 275°F for 2 hours.

- 4.5.7. Compact three individual specimens of each trial blend at the established compaction temperature of 275°F using 50 gyrations with the SGC in accordance with AASHTO T 312.
Note: The compacted sample must have a height of 115 ± 5 mm and be compacted in a standard 150 mm diameter Gyratory mold.
- 4.5.8. After the samples have been compacted and have cooled for at least 10 minutes in the gyratory molds under a fan, extrude them from the molds and allow them to cool. Determine the bulk specific gravity of each sample (G_{mb}) using the vacuum sealing method (AASHTO T 331) or geometric method given in AASHTO T 269 section 6.2.2.
- 4.5.8.1. Note: The minimum air voids requirement will vary depending on the method used to calculate specimen air voids.
- 4.5.9. Determine the theoretical maximum specific gravity (G_{mm}) of the uncompacted sample from each blend in accordance with AASHTO T 209. Calculate the percent air voids (V_a) and VCA_{MIX} as shown below:

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

$$VCA_{MIX} = 100 - \frac{G_{mb} \times P_{ca}}{G_{ca}}$$

Where:

P_{ca} = Percent of coarse aggregate in the mixture, based on the trial blend gradation

Note: This is the percent retained on the breakpoint sieve multiplied by the percent stone ($P_s = 100 - P_b$)

Note: The breakpoint sieve is defined as the finest sieve to retain at least 10 percent of the aggregate fraction. This is typically the #4 or #8 sieve depending on the grading of the blend.

G_{mb} = Bulk specific gravity of the compacted sample, determined in 4.5.8

G_{ca} = Bulk specific gravity of the coarse aggregate blend, determined in 4.4.2

- 4.5.10. Compare the VCA_{DRC} determined in Section 4.4.2 to the VCA_{MIX} determined in Section 4.5.9. When the VCA_{MIX} is equal to or less than VCA_{DRC} , then the blend has adequate stone-on-stone contact.
- 4.5.11. If all three trial blends have adequate stone-on-stone contact, select the blend with the highest air voids, making sure that the air void content is at least 15.0%. If the air void requirement is not met, additional blends and/or materials will need to be used.
- 4.6. Determining optimum binder content.
- 4.6.1. Once the optimum blend of materials has been selected, samples will need to be prepared and tested at three different binder contents at 0.5% intervals to determine the optimum binder content. A total of 4 samples will be produced at each binder

content: three compacted specimens for G_{mb} and Cantabro testing, and one for determination of G_{mm} .

Note: 2 additional samples of 1200 ± 200 grams will be needed for the draindown test after the optimum binder content is selected in Section 4.6.4.

- 4.6.2. Prepare the mixture samples as described in Sections 4.5.3 through 4.5.9, with the exception that the two samples (at each binder content) for draindown testing will not be conditioned as described in Section 4.5.6.
- 4.6.3. Test three compacted specimens at each binder content to determine the Cantabro abrasion loss in accordance with AASHTO T 401.
- 4.6.4. Select an optimum binder content with the lowest Cantabro loss that meets the requirements for air voids, VCA_{MIX} , and Cantabro loss as shown in section 4.8 Table 1.
Note: A way to find the AC% with the lowest Cantabro loss is to plot Cantabro loss on the vertical axis and AC% on the horizontal axis, then fit a curve to the data and select the point on the curve with the lowest Cantabro loss. You must test that this AC% meets all criteria given in section 4.8 table 1 .
- 4.6.5. Determine the draindown sensitivity of two uncompacted and unconditioned samples at the optimum binder content in accordance with ALDOT 386, with the exception that the testing temperatures will be at 325 and 350°F.
- 4.7. Evaluation of Moisture Sensitivity. Determine the moisture susceptibility of the designed mixture in accordance with ALDOT 361 with one freeze-thaw cycle. Modify ALDOT 361 as follows:
 - 4.7.1. Prepare six (6) x 115 mm high gyratory specimens at optimum binder content with 15 – 20% air voids by following ALDOT 361 to step 9.2.
Note: The specimens may be saw trimmed from one side to a total height of 95 +/- 5 mm in order to fit in a standard Lottman style indirect tensile strength breaking head
 - 4.7.2. For the conditioned subset apply a vacuum of 26 in. Hg (660 mm Hg) for 10 min to saturate the compacted specimens. No specific saturation level is required since saturation is impractical to determine for OGFC mixtures.
 - 4.7.3. Keep the specimens covered in water during the 16 hour freeze cycle.

Note: concrete cylinder molds work well for freezing gyratory specimens. Placing the mold in the hot water bath briefly after freezing helps to remove the specimen from the cylinder.
 - 4.7.4. Resume ALDOT-361 at step 9.6.
Note: If the mixture fails to meet the moisture susceptibility requirements, a change or increase in the anti-stripping additive may be necessary.

4.8. Design Criteria. Meet the criteria shown in Table 1.

Table 1 - OGFC Mixture Specification Criteria

Property	Requirement
Minimum Air Voids, % Vacuum Sealing Method	15.0
Minimum Air Voids, % Dimensional Analysis	17.0
VCA _{MIX} , %	Less than VCA _{DRC}
Conditioned Cantabro Loss, %	20.0 max
Tensile Strength Ratio (TSR)	0.70 min
Conditioned Tensile Strength, psi	50.0 min
Draindown, %	0.30 max

5. Reporting

5.1. The contractor shall submit to Materials and Tests the job mix formula for review. The contractor shall include all the data this procedure requires.

6. Appendix

Example OGFC Trial Blend Calculations

The gradations and bulk specific gravities (G_{sb}) are determined for each of the aggregate components. In addition, three trial blends are determined. An example gradation and blend percentages for only Trial Blend No. 1 are shown in Table A1.

Table A1: Blend No. 1 Component Gradations, Blend Percentages, and Bulk Specific Gravities:

Sieve	No. 67 Stone	No. 7 Stone	Screenings	BHF	Composite	Spec Range
	24%	69%	6%	1%	100%	
1"	100.0	100.0	100.0	100.0	100	
3/4"	97.5	100.0	100.0	100.0	99	100
1/2"	80.6	96.8	100.0	100.0	93	85 - 100
3/8"	58.2	63.6	100.0	100.0	65	55 - 65
No. 4	10.0	11.0	97.0	100.0	17	10 - 25
No. 8	2.8	4.2	72.1	100.0	9	5 - 10
No. 16	2.2	3.0	45.5	100.0	6	
No. 30	1.9	2.4	28.1	100.0	5	
No. 50	1.8	1.8	13.2	100.0	4	
No. 100	1.6	1.6	7.9	100.0	3	
No. 200	1.5	1.4	5.7	100.0	2.7	2 - 4
G_{sb}	2.790	2.722	2.630	2.717		

The bulk density (M) (also called the unit weight) and voids in the aggregate (VCA) for each of the coarse aggregate components are then determined as shown in Tables A2 and A3.

Note: Both the #67 Stone and #7 Stone are considered as coarse aggregate for the purposes of this design. The screenings and baghouse fines (BHF) are considered as fine aggregate.

Note: The unit weight test and calculation shown in Tables A2 and A3 could also be performed on a blended specimen – or aggregate batches – containing only the coarse portion of the blend. The G_{sb} value for the calculation would need to be the weighted average of the G_{sb} of the individual coarse aggregate stockpiles.

Table A2: Bulk Density (Unit Weight) and Voids in Aggregate for No. 67 Stone:

Property	Sample 1	Sample 2	Sample 3	Average
A) Wt. of Measure, kg	1.8522	1.8522	1.8522	
B) Wt. of Aggregate plus Measure, kg	6.4832	6.4589	6.4441	
C) Volume of Measure, m ³	0.00281	0.00281	0.00281	
D) Bulk Density of Aggregate, kg/m ³ = (B-A)/C	1,648	1,630	1,634	
E) Bulk Specific Gravity of Aggregate	2.790	2.790	2.790	
F) Density of Water, 998 kg/m ³	998	998	998	
Percent Voids (VCA) = 100 ((E*F)-D)/(E*F)	40.8	41.1	41.3	41.1

Table A3: Bulk Density (Unit Weight) and Voids in Aggregate for No. 7 Stone:

Property	Sample 1	Sample 2	Sample 3	Average
A) Wt. of Measure, kg	1.8520	1.8520		
B) Wt. of Aggregate plus Measure, kg	6.2169	6.2865		
C) Volume of Measure, m ³	0.00281	0.00281		
D) Bulk Density of Aggregate, kg/m ³ = (B-A)/C	1,553	1,578		
E) Bulk Specific Gravity of Aggregate	2.722	2.722		
F) Density of Water, 998 kg/m ³	998	998		
Percent Voids (VCA) = 100 ((E*F)-D)/(E*F)	42.8	41.9		42.4

The data is summarized as shown in Table A4.

Table A4: Summary of Data for Trial Blend No. 1:

Component	Blend %	G _{sb}	VCA (dry rodded)
No. 67 Stone	24	2.790 (T85)	41.1
No. 7 Stone	69	2.722 (T85)	42.4
Screenings	6	2.630 (T84)	
Baghouse	1	2.717 (T100)	
Blend	100	2.732	

Based on the blend percentages, the percent of coarse aggregate is determined for each of the coarse aggregate components as shown below:

The coarse aggregate specific gravity is then determined based on the following equation:

$$G_{CA} = \frac{(P_{s,1} + P_{s,2} + \dots + P_{s,N})}{\left(\left(\frac{P_{s,1}}{G_{CA,1}}\right) + \left(\frac{P_{s,2}}{G_{CA,2}}\right) + \dots + \left(\frac{P_{s,N}}{G_{CA,N}}\right)\right)}$$

Where:

x = Current Stockpile

N = Number of Coarse Stockpiles

P_s = Cold Feed Percentage, Coarse Stockpile (note: do not include fine aggregate or filler)

G_{CA} = Coarse Aggregate Specific Gravity (AASHTO T85)

$$G_{CA} = \frac{(24+69)}{\left(\left(\frac{24}{2.790}\right) + \left(\frac{69}{2.722}\right)\right)} = 2.739$$

The voids in the coarse aggregate, dry-rodded condition is then determined as follows:

$$VCA_{DRC} = \frac{(P_{s,1} + P_{s,2} + \dots + P_{s,N})}{\left(\left(\frac{P_{s,1}}{VCA_{DRC,1}}\right) + \left(\frac{P_{s,2}}{VCA_{DRC,2}}\right) + \dots + \left(\frac{P_{s,N}}{VCA_{DRC,N}}\right)\right)}$$

Where:

x = Current Stockpile

N = Number of Coarse Stockpiles

P_s = Cold Feed Percentage, Coarse Stockpile (note: do not include fine aggregate or filler)

VCA_{DRC} = Voids in Coarse Aggregate, Dry-Rodded Condition

$$VCA_{DRC} = \frac{(24+69)}{\left(\left(\frac{24}{41.1}\right) + \left(\frac{69}{42.4}\right)\right)} = 42.1\%$$

Three samples of the trial blend are then mixed, conditioned, compacted and the G_{mb} determined. One additional sample for the trial blend is also mixed and conditioned, and then the maximum specific gravity is determined. The results are shown in Table A5 for specimens mixed at 7.0% AC.

Table A5: G_{mb} and G_{mm} results for Trial Blend No. 1 at 7.0% AC:

Property	Value
Average G_{mb}	2.055
G_{mm}	2.480

The air voids and VCA_{MIX} are then calculated based on the following equations:

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

$$V_a = 100 \times \left(1 - \frac{2.055}{2.580}\right) = 17.1\%$$

$$VCA_{MIX} = 100 - \frac{G_{mb} \times P_{ca}}{G_{ca}}$$

$$P_{ca} = \left(\frac{100 - P_{bp}}{100}\right) \times \left(\frac{100 - P_b}{100}\right) \times 100$$

Where:

P_{bp} = Percent passing breakpoint sieve (%)

P_b = Total AC Content (%)

$P_{bp} = 16.8\%$ (Percent passing the #4 sieve for this example)

Note: The #4 sieve is the breakpoint sieve since it is the finest sieve with >10% retained

$P_b = 7.0\%$ AC

$$P_{ca} = \left(\frac{100 - 16.8}{100} \right) \times \left(\frac{100 - 7.0}{100} \right) \times 100 = 77.4\%$$

$$VCA_{MIX} = 100 - \frac{2.055 \times (77.4)}{2.739} = 42.0\%$$

In this example, the VCA_{MIX} (42.0%) is less than the VCA_{DRC} (42.1%), so the blend has stone-on-stone contact at the asphalt content of 7.0%. Note that the percent asphalt does impact the VCA_{mix} calculation. To lower the VCA_{mix} relative to the VCA_{drc} , an additional blend could be performed by coarsening the blend on the breakpoint sieve (#4 sieve for this example problem). In addition, the blend also has an air void content greater than 15.0% (by the vacuum sealing method) so it would be an acceptable blend.

The next steps would be to determine the optimum binder content, check the Cantabro loss, and determine the moisture susceptibility and draindown. Table A6 summarizes the G_{mb} , G_{mm} , V_a , and Cantabro results at three asphalt contents (6.0, 6.5, and 7.0%) for the same blend shown previously. Note these specimens have all been aged for 2 hours at 275°F. Table A6 shows the air voids criteria (15% minimum for the vacuum sealing method) were satisfied at all three AC contents, but the 7.0% AC content was the only AC content with a Cantabro loss below the 20% threshold. Hence, 7.0% AC is considered the optimum AC content moving forward with this blend.

Table A6: Air Voids and Cantabro Loss versus Binder Content (%)

Binder Content (%)	Aging Time (hrs)	Aging Temperature (°F)	G_{mb}	G_{mm}	Corelok Air Voids (%)	Cantabro Loss (%)
6.0	4	275	2.015	2.518	20.0	35.9
6.5	4	275	2.031	2.499	18.7	21.2
7.0	4	275	2.055	2.480	17.1	15.8
				Criteria:	>15.0 (vacuum)	< 20

Table A7 summarizes the draindown, indirect tensile strength (ITS), and TSR results for the blend at the trial optimum AC content of 7.0%. This blend had a draindown below the maximum of 0.3%, a wet ITS above the 50 psi minimum, and a TSR above the 0.70 minimum. Hence, this blend is considered acceptable for design.

Table A7: Summary of Draindown, Indirect Tensile Strength (ITS), and TSR results

<i>Test</i>	<i>Result</i>	<i>Criteria</i>
<i>Draindown (%)</i>	0.02	max 0.3%
<i>ITS wet (psi)</i>	60.6	min 50 psi
<i>ITS dry (psi)</i>	66.8	n/a
<i>TSR</i>	0.91	min 0.70