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## CHAPTER 1

### Selection of Aggregates

The first step of any design is to determine what materials are available. This includes selecting coarse and fine aggregate sources and ensuring there is an adequate supply of each. Where practical, multiple aggregate sources (coarse and fine) should be used. Using multiple aggregate sources allows more control during mix design and, ultimately, during production. Another factor to consider is whether Recycled Asphalt Pavement (RAP) will be included in the design. A recommended practice for design is to prepare separate designs for mixes with RAP and those without RAP. This provides greater flexibility during production.

The next step is to sample the aggregates from the stockpiles. This should be done in accordance with AASHTO T2. Once all the materials have been sampled there are several properties that will be tested. The properties are divided into two categories, Source Properties (Table 1) and Consensus Properties (Table 2). Source Properties are verified biannually or more frequently if the history of a property has shown fluctuations.

**TABLE 1. Source Properties of Aggregates**

Source Property	Test Method
Toughness	L. A. Abrasion (AASHTO T96)
Soundness	Magnesium Sulfate Soundness (AASHTO T104)
Deleterious Materials: *	
Clay Particles	Clay Lumps and Friable Particles (AASHTO T 112)
Lightweight Materials	Lightweight Pieces in Aggregate (AASHTO T 113)

\* Only tested as needed.

Consensus Properties are typically run on individual aggregates used for the mix design. However, it is the blended values that govern the results. This allows materials that do not meet an individual property to be used if the total blend meets the defined criteria. To determine which properties need to be tested on each aggregate fraction, refer to Section 211.02 of the *Road and Bridge Specifications*.

**TABLE 2. Consensus Properties of Aggregates**

<b>Consensus Property</b>	<b>Test Method</b>
Flat and Elongated Particles	ASTM D 4791
Coarse Aggregate Angularity	ASTM D 5821
Fine Aggregate Angularity	Uncompacted Void Content AASHTO T 304
Sand Equivalent	AASHTO T 176

Besides the Source and Consensus Properties there is also a Gradation Analysis and Specific Gravity determination. These properties should be evaluated frequently due to variability in aggregate production at the quarry. Never assume an aggregate test result, that may be only a month old, will still be accurate for the individual stockpiles at the plant.

For this example an SM-9.5A mix will be designed. The design will consist of three aggregate sources, one coarse and two fine. The coarse aggregate will consist of No. 8 aggregate and the fine aggregates will be No. 10 aggregate and natural sand. In addition to using coarse and fine aggregates the mix design technician should account for plant breakdown by incorporating baghouse fines into the blend.

After all of the materials have been sampled they should be oven dried at  $230^{\circ} \pm 9^{\circ}$  F. Once dried the samples are cooled to room temperature, then reduced to testing size in accordance with AASHTO T 248.

After reducing the aggregate to the proper testing size the first test performed in this example will be a washed gradation. Washing the sample will be done in accordance with AASHTO T 11 and the sieve analysis in accordance with AASHTO T 27.

**Author's Note:** IT IS NOT INTENT OF THIS MANUAL TO FULLY EXPLAIN EACH TEST PROCEDURE. THE MIX DESIGN TECHNICIAN SHOULD ALWAYS REFERENCE AASHTO OR ASTM FOR THE COMPLETE PROCEDURES.

### **Gradation (Sieve) Analysis (AASHTO T 27):**

When performing a sieve analysis, care should be taken not to overload each sieve. AASHTO T 27 Section 8.3 specifies weight limitations for each sieve (Table 3).

**TABLE 3. Maximum sample weights for selected standard sieves.**

<b>Gradation / Sieve Analysis AASHTO T 27</b>		
<b>Sieve Size</b>	<b>Maximum Weight Allowed 8 in. Sieve</b>	<b>Maximum Weight Allowed 12 in. Sieve</b>
Less than No. 4	200	469
No. 4 (4.75mm)	330	800
$\frac{3}{8}$ in. (9.5mm)	670	1590
$\frac{1}{2}$ in. (12.5mm)	890	2090
$\frac{3}{4}$ in. (19.0mm)	1350	3180

Note: Typically 12-inch diameter sieves are used for coarse aggregate and mixture (furnace burn samples) gradation so not to overload any sieve especially the No. 4 sieve.

The prewashed, preweighed sample is placed on the top sieve, and the entire nest of sieves is placed in a mechanical sieve shaker. The mechanical shaker provides the necessary movement to allow the sample to separate through the nest of sieves. When the shaker is complete the material on each sieve is removed, weighed and individually recorded.

The first gradation to be completed will be that of the No. 8 aggregate. After performing the sieve analysis the gradation is as follows:

Dry weight of the original sample (before washing):			1172.3 g
Dry weight of sample after washing:			1161.2 g
Sieve Size	Weight (g) Retained	Percent Retained	Percent Passing
½ in. (12.5mm)	0.0	0.0	100.0
⅜ in. (9.5mm)	119.6	10.2	89.8*
No. 4 (4.75mm)	793.6	67.6	22.1*
No. 8 (2.36mm)	193.4	16.5	5.6
No. 16 (1.16mm)	42.2	3.6	2.0
No. 30 (600µm)	2.4	0.2	1.8
No. 50 (300µm)	2.3	0.2	1.6
No. 100 (150µm)	4.7	0.4	1.2
No. 200 (75µm)	3.6	0.3	0.9
Pan	0.5	0.0	N/A
Sum	1162.3		

\* Because the No. 8 aggregate is considered to be a coarse aggregate, the material retained on these sieves should be kept separate for consensus property testing

The percent retained on any individual sieve is calculated by:

$$\% \text{ retained} = \frac{\text{weight retained}}{\text{dry wt. before washing}} \times 100$$

Example: Calculate the % Retained on the No. 16 sieve for the No. 8 Aggregate (above).

$$\% \text{ Retained on No. 16 sieve} = (42.2 / 1172.3) \times 100 = 3.6 \%$$

Determining the values for percent passing column in the gradation analysis begins with calculating the percent passing the No. 200 sieve.

$$\% \text{ passing \#200} = \frac{(\text{dry wt. before washing} - \text{dry wt. after washing} + \text{wt. retained in pan})}{\text{dry wt. before washing}} \times 100$$

Example: Calculate the Percent Passing the No. 200 sieve for the No. 8 Aggregate (above).

$$\% \text{ Passing \#200} = \frac{(1172.3 - 1161.2 + 0.5)}{1172.3} \times 100 = \frac{11.6}{1172.3} \times 100$$

$$\% \text{ Passing \#200} = 0.9$$

Calculating the Percent Passing for other sieves is done by adding the Percent Retained and Percent Passing values for the sieve below it in the analysis table.

Example: Find the % Passing for the No. 100 sieve for the No. 8 aggregate (above).

$$\begin{aligned}\% \text{ passing \#100} &= \% \text{ retained on \#200} + \% \text{ passing \#200} \\ &= 0.3 + 0.9 \\ &= 1.2\end{aligned}$$

Example: Find the % Passing for the No. 4 sieve for the No. 8 aggregate (above).

$$\begin{aligned}\% \text{ Passing \#4} &= \% \text{ retained on \#8} + \% \text{ passing \#8} \\ &= 16.5 + 5.6 \\ &= 22.1\end{aligned}$$

Next, complete a gradation on the two fine aggregate sources and the bag house fines. Calculating the percent retained and percent passing on these materials follows the procedure just shown for the No. 8 aggregate.

The wash gradation on the No.10 Aggregate is as follows:

Dry weight of the original sample (before washing):			852.3 g
Dry weight of sample after washing:			777.5 g
Sieve Size	Weight (g) Retained	Percent Retained	Percent Passing
½ in. (12.5mm)	0.0	0.0	100.0
¾ in. (9.5mm)	0.0	0.0	100.0
No. 4 (4.75mm)	51.1	6.0	94.0
No. 8 (2.36mm)	289.8	34.0	60.0*
No. 16 (1.16mm)	187.5	22.0	38.0*
No. 30 (600µm)	110.8	13.0	25.0*
No. 50 (300µm)	59.7	7.0	18.0*
No. 100 (150µm)	51.0	6.0	12.0*
No. 200 (75µm)	24.8	2.9	9.1
Pan	2.6	0.3	N/A
Sum	777.3		

\* Save all the material from No. 8 (2.36mm) sieve through the No. 100 (150µm) sieve, in individual containers, to test for Uncompacted Void Content of Fine Aggregate, AASHTO T 304 Method A.

The wash gradation on the Natural Sand is as follows:

Dry weight of the original sample (before washing):			741.3 g
Dry weight of sample after washing:			730.4 g
Sieve Size	Weight (g) Retained	Percent Retained	Percent Passing
½ in. (12.5mm)	0.0	0.0	100.0
⅜ in. (9.5mm)	0.0	0.0	100.0
No. 4 (4.75mm)	7.3	1.0	99.0
No. 8 (2.36mm)	96.2	13.0	86.0*
No. 16 (1.16mm)	133.6	18.0	68.0*
No. 30 (600µm)	133.7	18.0	50.0*
No. 50 (300µm)	244.3	33.0	17.0*
No. 100 (150µm)	96.8	13.1	4.0*
No. 200 (75µm)	18.2	2.5	1.5
Pan	0.5	0.1	N/A
Sum	730.6		

\* Save all the material from No. 8 (2.36mm) sieve through the No. 100 (150µm) sieve, in individual containers, to test for Uncompacted Void Content of Fine Aggregate, AASHTO T 304 Method A.

The wash gradation on the Bag House Fines is as follows:

Dry weight of the original sample (before washing):			111.3 g
Dry weight of sample after washing:			N/A
Sieve Size	Weight (g) Retained	Percent Retained	Percent Passing
No. 16 (1.16mm)	0.0	0.0	100.0
No. 30 (600µm)	0.0	0.0	100.0
No. 50 (300µm)	0.0	0.0	100.0
No. 100 (150µm)	0.0	0.0	100.0
No. 200 (75µm)	11.1	10.0	90.0
Pan	0.0	0.0	N/A
Sum	11.1		

\* Only the gradation is required on the bag house fines. The gradation is done in accordance to Sieve Analysis of Mineral Filler for Bituminous Paving Mixtures, AASHTO T 37.

### **Specific Gravity:**

Specific Gravity is the ratio of the mass of a given volume of aggregate to the mass of an equal volume of distilled water at the same temperature. It is an essential aggregate property used in mix design calculations. Aggregate specific gravity testing involves immersing aggregates in water to determine the mass of solid volume used to calculate specific gravity.

The various tests for aggregate specific gravity are:

<b>Material</b>	<b>Test Procedure</b>
Coarse Aggregate	AASHTO T 85
Fine Aggregate	AASHTO T 84
Mineral Filler (Bag House Fines)	AASHTO T 100

In HMA mix design calculations, there are three distinct aggregate specific gravities: bulk, effective, and apparent. The aggregate particle shown in Figure 1 illustrates the mass and volumes used to determine each of these specific gravities. Bulk and apparent specific gravities reflect aggregate volumes as measured by water immersion.

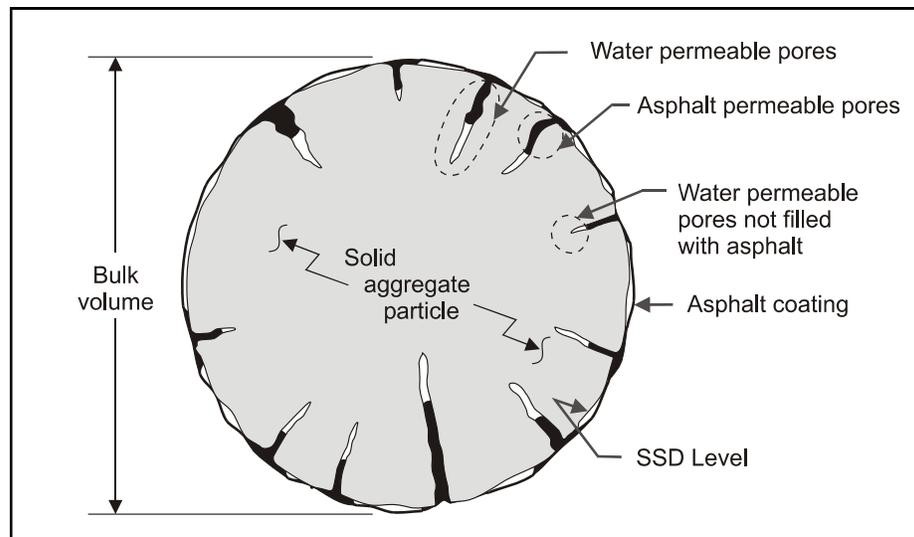


Figure 1. Illustration of an aggregate particle for use in determining specific gravities.

$$\text{Specific Gravity} = \frac{\text{aggregate density}}{\text{density of water}} \quad [\text{density} = \text{mass} / \text{volume}]$$

$$\text{Dry Bulk Specific Gravity } (G_{sb}) = \frac{\text{Weight of Dry Aggregate}}{\text{Bulk Volume}}$$

$$\text{Effective Specific gravity } (G_{se}) = \frac{\text{Weight of Dry Aggregate}}{\left( \text{Volume of Solid Aggregate} + \frac{\text{Volume of Water Permeable Pores Not Filled with Asphalt}}{\text{Density of Water}} \right)}$$

$$\text{Apparent Specific Gravity } (G_{sa}) = \frac{\text{Weight of Dry Aggregate}}{\text{Volume of Solid Aggregate}}$$

Bulk specific gravity includes the entire aggregate volume including solid volume and the volume of pores that are permeable (filled with water). The bulk volume is the largest aggregate volume measured. Thus, the bulk specific gravity is, numerically, the lowest among the three.

Apparent specific gravity only includes the solid aggregate volume. It does not include the volume of water permeable pores. Since its volume is the smallest, apparent specific gravity is, numerically, the largest specific gravity.

Effective specific gravity is not measured by immersing aggregate in water. Instead, it is determined during the mix design phase based on properties of a voidless asphalt and aggregate mixture (maximum theoretical specific gravity). The effective volume is the solid aggregate volume and the volume of pores that are not permeable to liquid asphalt. Thus, effective specific gravity recognizes the difference between water and asphalt permeable pores and is a very important property. Because the volume is between the bulk and apparent volumes, the effective specific gravity is, numerically, between these two values.

### **Specific Gravity and Absorption of Coarse Aggregate (AASHTO T 85)**

The coarse aggregate material should be sampled, oven-dried, and reduced to testing size in accordance with AASHTO procedures (AASHTO T 2 and T 248). Once you have your representative sample of material the first step is to wash the sample over the No. 4 sieve. This can be done in one step or by dry sieving and then washing all the +4 material.

NOTE: IF AN AGGREGATE SOURCE HAS A LARGE QUANTITY OF MATERIAL RETAINED ON THE NO. 8 SIEVE, THAT MATERIAL MAY BE INCLUDED IN THE COARSE AGGREGATE SPECIFIC GRAVITY.

Next, immerse the washed sample in water for 15 to 19 hours. Remove the sample from the water and roll in a towel until all visible films of water are removed. Take care not to remove water from the pores in the aggregate. Weigh the sample in this Saturated Surface Dry (SSD) condition. Immediately place the SSD sample in a basket and immerse in a water bath for 10 minutes and then record the weight. Remove the sample from the basket (return basket to the water bath and record its weight in water) and place the sample in an oven to dry. Allow the sample to cool, and then record dry sample weight.

Coarse Aggregate Specific Gravity Calculations: (always report specific gravities to nearest 0.001 and absorptions to 0.01%)

A = mass (weight) of oven - dry sample in air, g

B = mass (weight) of saturated -surface-dry sample in air, g

C = mass (weight) of saturated sample in water, g

Dry Bulk Specific Gravity ( $G_{sb}$ ): 
$$G_{sb} = \frac{A}{(B - C)}$$

Apparent Specific Gravity ( $G_{sa}$ ): 
$$G_{sa} = \frac{A}{(A - C)}$$

Absorption: 
$$\text{Absorption}(\%) = \left[ \frac{(B - A)}{A} \right] \times 100$$

Example:

A sample calculation for the specific gravities and absorption for the No. 8 aggregate:

Test Data:

SSD Sample and Pan		2554.7 g
Pan		<u>-226.5 g</u>
SSD weight in air	“B”	2328.2 g
Basket and Aggregate Under Water		2785.2 g
Basket Under Water		<u>-1340.5 g</u>
Sample Under Water (calculated)	“C”	1444.7 g
Pan and Oven-Dry Aggregate		2533.6 g
Pan		<u>-226.5 g</u>
Oven Dry Sample	“A”	2307.1 g

Using the equations given above, the specific gravity calculations are as follows:

$$\text{Dry Bulk Specific Gravity (G}_{sb}\text{): } G_{sb} = \frac{2307.1}{(2328.2 - 1444.7)}$$

$$G_{sb} = \frac{2307.1}{883.5}$$

$$G_{sb} = 2.611$$

Apparent Specific Gravity (G<sub>sa</sub>):

$$G_{sa} = \frac{2307.1}{(2307.1 - 1444.7)}$$

$$G_{sa} = \frac{2307.1}{862.4}$$

$$G_{sa} = 2.675$$

Absorption:

$$\text{Absorption} = \left[ \frac{(2328.2 - 2307.1)}{2307.1} \right] \times 100$$

$$\text{Absorption} = \left[ \frac{21.1}{2307.1} \right] \times 100$$

$$\text{Absorption} = 0.00914 \times 100$$

$$\text{Absorption} = 0.91\%$$

NOTE: The Effective Specific Gravity (G<sub>se</sub>) cannot be determined until the aggregate has been mixed with the liquid asphalt and a Maximum Theoretical Specific Gravity (G<sub>mm</sub>) has been found.

**Specific Gravity and Absorption of Fine Aggregate (AASHTO T84)**

The fine aggregate material should be sampled, oven-dried, and reduced to testing size in accordance with AASHTO procedures (T 2 and T 248). For a fine aggregate specific gravity test we will need approximately 1000g of -4 material. The sample should always be sieved through the No. 4 sieve to ensure all the coarse material has been removed. The sample is first immersed in water for 15 to 19 hours.

After the sample has been soaked for 15 to 19 hours pour off the excess water with care not to lose any fines. In order to continue to remove the water to test for the Saturated-Surface-Dry (SSD) condition, the sample should be exposed to a gentle flow of warm air, stirring frequently to ensure even drying throughout the sample.

The SSD condition of the sample is measured by means of a cone and tamp test. The cone is placed on a smooth, flat, firm, and nonabsorbent surface. The cone is loaded to overflowing with the sample. Then apply 25 drops with a tamper at a height of 0.2 in. (5mm) from the surface of the sample. Adjust the starting height for the tamper to the new surface elevation after each drop and distribute the drops over the available sample surface.

Remove the cone and visually inspect the sample to determine if a slight slump has occurred. If there is a slight slump then the sample is determined to be at the SSD condition.

**Defining “slight slump”:** VDOT has adopted a procedure for judging when the SSD condition has been reached in this test. This is not given in the test specification (AASHTO T 84). The SSD condition is reached when the cone of aggregate slumps leaving a central column of aggregate still standing that is between 5/8” and 1” in diameter. The tamper used in this test is about 1” in diameter on the bottom and 5/8” diameter at the top making it a good reference.

If the cone test slumps too little – that is, the column of aggregate still standing is larger than 1” in diameter - the aggregate is still too moist. Allow the material to continue drying and repeat the cone test until the SSD condition is reached. (The full specification (AASHTO T 84) gives alternative ways to determine the SSD condition for materials that do not readily slump.)

If the cone test slumps too much – the column of aggregate still standing is less than 5/8” in diameter - the sample is too dry. It should be moistened, covered and then set aside for 30 minutes to allow for re-absorption. After 30 minutes, resume the cone and tamp test to determine the SSD condition.

Once SSD condition has been reached immediately weigh  $500 \pm 10$  grams into a separate container. Then partially fill a pycnometer with water and carefully add the SSD sample. Fill the pycnometer slightly below the calibration mark with water. Remove all entrapped air (i.e. air bubbles) and continue to fill with water to the calibration mark. Adjust sample temperature to  $73.4^{\circ}\text{F} \pm 3^{\circ}$  before weighing. This can be achieved by using a water bath. Weigh the pycnometer, with SSD sample, and water. Record the total weight of the pycnometer, SSD sample and water.

Remove sample from pycnometer and place in pan. Place the pan with sample in an oven and dry to a constant weight. Once dry, remove from the oven and allow it to cool to room temperature for  $1.0 \pm 0.5$  hours, then record the mass of the sample.

Fine Aggregate Specific Gravity Calculations: (always report specific gravity to nearest 0.001 and absorption to 0.01%)

A = mass (weight) of oven - dry specimen in air, g

B = mass (weight) of pycnometer filled with distilled water to calibration mark, g

C = mass (weight) of pycnometer with sample and water to calibration mark, g

S = mass (weight) of saturated - surface - dry sample, g

$$\text{Dry Bulk Specific Gravity (G}_{\text{sb}}\text{): } G_{\text{sb}} = \frac{A}{(B + S - C)}$$

$$\text{Apparent Specific Gravity (G}_{\text{sa}}\text{): } G_{\text{sa}} = \frac{A}{(B + A - C)}$$

Absorption:

$$\text{Absorption (\%)} = \left[ \frac{(S - A)}{A} \right] \times 100$$

Example:

A sample calculation for the specific gravities and absorption for the No. 10 aggregate:

Test Data:

SSD Sample and Pan		652.6 g
Pan		-152.6 g
SSD weight in air	“S”	500.0 g
Pycnometer with Sample and Water	“C”	1571.5 g
Pycnometer with Water to calibration mark	“B”	1260.2 g
Pan and Oven-Dry Aggregate		981.5 g
Pan		-486.4 g
Oven Dry Sample	“A”	495.1 g

Dry Bulk Specific Gravity ( $G_{sb}$ ):

$$G_{sb} = \frac{495.1}{(1260.2 + 500.0 - 1571.5)}$$

$$G_{sb} = \frac{495.1}{188.7}$$

$$G_{sb} = 2.624$$

Apparent Specific Gravity ( $G_{sa}$ ):

$$G_{sa} = \frac{495.1}{(1260.2 + 495.1 - 1571.5)}$$

$$G_{sa} = \frac{495.1}{183.8}$$

$$G_{sa} = 2.694$$

Absorption:

$$\text{Absorption} = \left[ \frac{(500.0 - 495.1)}{495.1} \right] \times 100$$

$$\text{Absorption} = \left[ \frac{4.9}{495.1} \right] \times 100$$

$$\text{Absorption} = 0.00989 \times 100$$

$$\text{Absorption} = .99 \%$$

Now that all our gradations and specific gravities are complete we can proceed with the other Consensus Property tests on our aggregates. From each gradation we have fractionated materials that need testing: The No. 8 material requires a Flat and Elongated analysis on the 3/8 in. and No. 4 sized particles, and both the natural sand and No. 10 (quarry dust) require a Fine Aggregate Angularity measurement.

**Flat and Elongated Particles (ASTM D 4791):**

This test is run on individual particles that have been fractionated and reduced down to approximately 100 particles of each sieve-sized material greater than the No. 4 sieve in accordance with VTM-121. A maximum to minimum dimension-ratio is measured on each particle using a proportional caliper device (Figure 2). With this analysis the particles are divided into two piles, passing or failing, based on the ratio setting of the caliper. Each pile is then weighed and the weight (grams) recorded. The percentage of failing material is calculated.

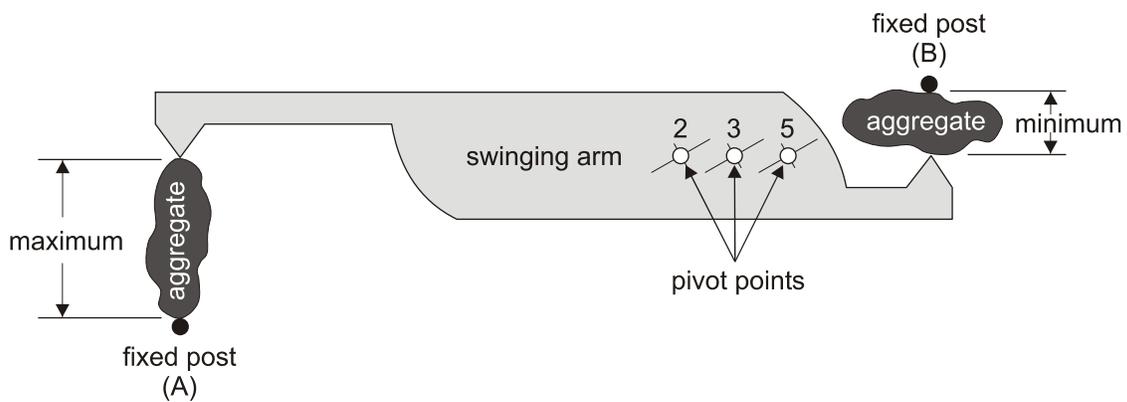


Figure 2. Caliper device used in identifying flat and elongated (F&E) aggregate particles.

Based on the results from the gradation on the No.8 aggregate we need to measure both the 3/8 in. and No. 4 sieve size material (See section 211.02 of *Road and Bridge Specifications*). If necessary, additional material may need to be sieved down or a reduction in the quantity of particles tested in order to obtain approximately 100 particles for each sieve size. Now we are ready to measure each particle. This is done with a proportional caliper (Figure 2) where first the maximum length is measured then the minimum thickness is checked at the ratio setting on the calipers. From the analysis we now have a passing and failing pile of material that can each be weighed.

In the table are the results from the gradation on our No. 8 aggregate. Notice the Percent Passing and Percent Retained columns have been interchanged to simplify calculations. First we need to determine the total percent retained on the No. 4 sieve.

Total % Retained on No. 4 Sieve = Sum of No. 4 and Larger Sieves

Total % Retained on No. 4 Sieve = 67.7 + 10.2 + 0.0

Total % Retained on No. 4 Sieve = 77.9 %

Gradation				Flat and Elongated Particles				
Sieve Size	Weight Retained	Percent Passing	Percent Retained	+ 4 % Retained	Testing Weight	F&E Weight	F&E Percent	Weighted Average
½ in.	0.0	100.0	0.0					
3/8 in.	119.6	89.8	10.2					
No. 4	793.6	22.1	67.7					
		Total	<b>77.9 %</b>					

Now we need to determine what percentage of the Total % Retained on No. 4 Sieve is ultimately retained on a larger sieve (1/2in, 3/8in., etc).

$$\% \text{ of } + 4 \text{ Material Retained on Larger Sieves} = \frac{\% \text{ Retained on Larger Sieve}}{\text{Total \% Retained on No. 4 Sieve}} \times 100$$

$$\% \text{ of } + 4 \text{ Material Retained on } 3/8 \text{ in. Sieve} = \frac{10.2}{77.9} \times 100$$

$$\% \text{ of } + 4 \text{ Material Retained on } 3/8 \text{ in. Sieve} = 0.1309 \times 100$$

$$\% \text{ of } + 4 \text{ Material Retained on } 3/8 \text{ in. Sieve} = 13.1 \%$$

$$\% \text{ of } + 4 \text{ Material Retained on No. 4 Sieve} = \frac{67.7}{77.9} \times 100$$

$$\% \text{ of } + 4 \text{ Material Retained on No. 4 Sieve} = 0.8690 \times 100$$

$$\% \text{ of } + 4 \text{ Material Retained on No. 4 Sieve} = 86.9 \%$$

Gradation				Flat and Elongated Particles (5 to 1 Ratio)				
Sieve Size	Weight Retained	Percent Passing	Percent Retained	+ 4 % Retained	Testing Weight	F&E Weight	F&E Percent	Weighted Average
½ in.	0.0	100.0	0.0	<b>0.0</b>				
3/8 in.	119.6	89.8	10.2	<b>13.1%</b>				
No. 4	793.6	22.1	67.7	<b>86.9%</b>				
		Total	77.9					

Note: As a check, the total of the +4 % Retained column should equal 100 or be extremely close taking into account rounding errors.

As discussed earlier we will only be testing approximately 100 particles of each sieve size. The weight (grams) of those particles is considered the testing weight for each sieve size and should be recorded. We can continue with the maximum to minimum determination for each particle and adding them to either the passing or failing pile. Once the analysis is complete both the passing and failing piles are weighed. The sum of the weights should equal the original testing weight for that size material. The weight (grams) of the failing (F&E) pile will be recorded, and then we can calculate the Flat and Elongated ratio we were evaluating.

Gradation				Flat and Elongated Particles (5 to 1 Ratio)				
Sieve Size	Weight Retained	Percent Passing	Percent Retained	+ 4 % Retained	Testing Weight	F&E Weight	F&E Percent	Weighted Average
½ in.	0.0	100.0	0.0					
3/8 in.	119.6	89.8	10.2	13.1%	119.6	1.6		
No. 4	793.6	22.1	67.7	86.9%	59.4	1.9		
		Total	77.9					

$$\text{F \& E \% for the Sieve Size} = \frac{\text{F \& E Weight}}{\text{Testing Weight}} \times 100$$

$$\text{F \& E \% for the 3/8 in. Sieve} = \frac{1.6}{119.6} \times 100$$

$$\text{F \& E \% for the 3/8 in. Sieve} = 0.0133 \times 100$$

$$\text{F \& E \% for the 3/8 in. Sieve} = 1.33 \%$$

$$\text{F \& E \% for the No. 4 Sieve} = \frac{1.9}{59.4} \times 100$$

$$\text{F \& E \% for the No. 4 Sieve} = 0.0320 \times 100$$

$$\text{F \& E \% for the No. 4 Sieve} = 3.20 \%$$

Gradation				Flat and Elongated Particles (5 to 1 Ratio)				
Sieve Size	Weight Retained	Percent Passing	Percent Retained	+ 4 % Retained	Testing Weight	F&E Weight	F&E Percent	Weighted Average
½ in.	0.0	100.0	0.0					
3/8 in.	119.6	89.8	10.2	13.1	119.6	1.6	<b>1.33%</b>	
No. 4	793.6	22.1	67.7	86.9	59.4	1.9	<b>3.20%</b>	
		Total	77.9					

The weighted average for each individual sieve size is determined by multiplying the percent plus No. 4 sieve retained on that sieve size by the percent F&E on that sieve size.

$$\text{Weighted Average} = \frac{\text{+ 4 \% Retained for that Sieve Size}}{100} \times (\text{F \& E Percent for that Sieve Size})$$

$$\text{Weighted Average for the 3/8 in. Sieve} = \frac{13.1}{100} \times 1.33$$

$$\text{Weighted Average for the 3/8 in. Sieve} = 0.131 \times 1.33$$

$$\text{Weighted Average for the 3/8 in. Sieve} = 0.17 \%$$

$$\text{Weighted Average for the No. 4 Sieve} = \frac{86.9}{100} \times 3.20$$

$$\text{Weighted Average for the No. 4 Sieve} = 0.869 \times 3.20$$

$$\text{Weighted Average for the No. 4 Sieve} = 2.78 \%$$

Gradation				Flat and Elongated Particles (5 to 1 Ratio)				
Sieve Size	Weight Retained	Percent Passing	Percent Retained	+ 4 % Retained	Testing Weight	F&E Weight	F&E Percent	Weighted Average
½ in.	0.0	100.0	0.0					
3/8 in.	119.6	89.8	10.2	13.1	119.6	1.6	1.33	<b>0.17%</b>
No. 4	793.6	22.1	67.7	86.9	59.4	1.9	3.20	<b>2.78%</b>
		Total	77.9	<b>*Total % F &amp; E</b>				<b>2.95%</b>

\*The Total Percent of Flat and Elongated Particles (5 to 1 Ratio) is the sum of the Weighted Averages.

**Determining the Percentage of Fractured Particles in Coarse Aggregate (ASTM D 5821)**

This property is normally only tested on gravel sources. If your material is mined from a quarry where the material has to be blasted before it is crushed there typically is no need to run this test and you can report 100 percent passing.

**Fine Aggregate Angularity (FAA) as determined by:  
Uncompacted Void Content of Fine Aggregate (AASHTO T 304) - Method A**

This procedure is intended to give an angularity measurement for fine aggregates. Fine Aggregate Angularity (FAA) is defined as the percent air voids of loosely compacted aggregate. The theory behind the FAA test is that uncompacted materials that are angular will produce greater air voids than rounded materials in the same volume. The fear is that rounded materials may promote rutting.

From our gradations on the fine aggregate (No.10 and natural sand), each individual sieve size-sized material should be kept separate for determining FAA. When this material is cleaned out of the sieves extreme caution should be taken so as to not include any particles that may be damaged while brushing the sieve.

In AASHTO T 304 Method A there is a predetermined blend of particle sizes to be tested (Table 4). Once the materials have been blended they need to be mixed with a spatula until they appear homogenous but careful not to damage any particles in the process. This blend of materials is then loaded into the funnel, leveled off with a spatula, and allowed to fall freely into the measure (Figure 3). Without any vibration the measure is struck off with one smooth pass of the spatula. The outside of the measure is brushed clean and then weighed.

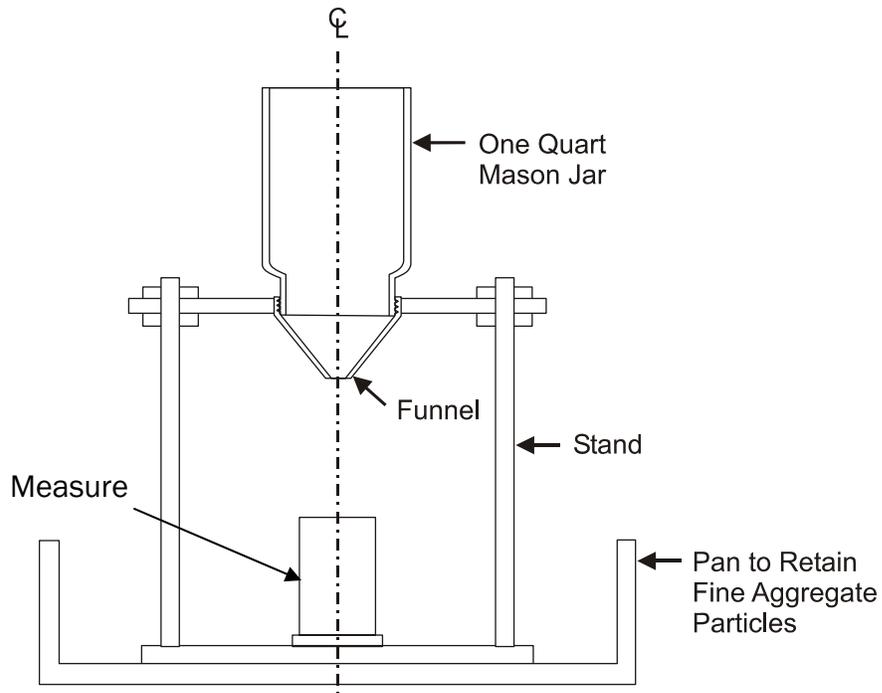


Figure 3. Section through center of apparatus used in testing Fine Aggregate Angularity (AASHTO T 304)

**TABLE 4. Predetermined blend of fine aggregate for AASHTO T 304**

Sieve Size	Weight
-8 +16	44 g
-16 +30	57 g
-30 +50	72 g
-50 + 100	17 g
Total	190 g

Note on Sample preparation: If you need more material of a particular sieve size to complete the blend make sure the material is obtained from a second washed gradation to ensure the material is clean and dry

The material is then recombined with the excess from the first test, remixed and the test performed a second time. The resulting FAA value will be calculated as an average of the two test results. The Dry Bulk Specific Gravity of the material is needed to calculate FAA.

The percent of uncompact voids is calculated by:

$$U = \frac{V - (F/G)}{V} \times 100$$

Where :

U = percent of uncompact voids in material

V = volume of measure, ml

F = weight of material in measure

G = dry bulk specific gravity of material

Example:

Sample calculation of Fine Aggregate Angularity of the No.10 material:

First Test Results

390.4 = weight of material and measure	100.4ml = volume of measure
-256.1 = weight of measure	2.624 = dry bulk specific gravity
134.3 = weight of material in measure	

$$U1 = \frac{100.4 - (134.3 / 2.624)}{100.4} \times 100$$

$$U1 = \frac{100.4 - 51.18}{100.4} \times 100$$

$$U1 = \frac{49.22}{100.4} \times 100$$

$$U1 = .4902 \times 100$$

$$U1 = 49.0\%$$

## Second Test Results

390.7 = weight of material and measure - <u>256.1</u> = weight of measure 134.6 = weight of material in measure	100.4ml = volume of measure 2.624 = dry bulk specific gravity
---	--

$$U2 = \frac{100.4 - (134.6 / 2.624)}{100.4} \times 100$$

$$U2 = \frac{100.4 - 51.30}{100.4} \times 100$$

$$U2 = \frac{49.10}{100.4} \times 100$$

$$U2 = .4890 \times 100$$

$$U2 = 48.9 \%$$

Report FAA for No.10:

$$\text{Average FAA} = \frac{U1 + U2}{2}$$

$$\text{Average FAA} = \frac{49.0 + 48.9}{2}$$

$$\text{Average FAA} = 49.0 \%$$

Example:

The Fine Aggregate Angularity of the Natural Sand is as follows:

## First Test Run

396.4 = weight of material and measure - <u>256.1</u> = weight of measure 140.3 = weight of material in measure	100.4ml = volume of measure 2.588 = dry bulk specific gravity
---	--

Calculated FAA (U1) = 46.0 % (check this result as practice)

## Second Test Run

396.1 = weight of material and measure - <u>256.1</u> = weight of measure 140.0 = weight of material in measure	100.4ml = volume of measure 2.588 = dry bulk specific gravity
---	--

Calculated FAA (U2) = 46.1 % (check this result as practice)

Report FAA for this Natural Sand:

$$\text{Average FAA} = (U1 + U2) / 2$$

$$\text{Average FAA} = (46.0 + 46.1) / 2 = 46.1$$

Thus, FAA = 46.1%

**Clay Content as determined by:  
Sand Equivalent Test (AASHTO T 176)**

The clay content is important in a mix design because clay will affect bonding of binder to the aggregates. Clay Content is determined in accordance with “Plastic Fines in Graded Aggregates and Soils by the Use of the Sand Equivalent Test AASHTO T176”.

The material should be reduced to proper testing size with extreme caution, as any segregation will affect the test results. The dry sample is then placed on a clean surface and a 3-ounce tin is filled to overflowing. The material is consolidated and leveled off even with the top of the tin. Charge the testing cylinder with 4.0 in. of calcium chloride solution and add the test sample. Tap the bottom of the cylinder several times, sharply, and allow it to stand undisturbed for 10 minutes.

After 10 minutes, add the stopper to the top of the cylinder, loosen the material from the bottom, and load into a mechanical shaker. This will apply the standard shaking action for 45 seconds. After shaking, set the cylinder upright on the table and remove the stopper. Insert the irrigator tube down the cylinder and penetrate through the sample in a manner as to promote the fine materials into suspension above the coarser particles. Allow the cylinder and contents to stand undisturbed for 20 minutes.

At this time you can take the clay reading at the interface between the clear solution and the cloudy solution containing suspended fine material. Then insert the weighted foot, which will penetrate through the suspended clay layer and sit on top of the sediment aggregate layer. The interface between these two layers is the sand reading (Figure 4).

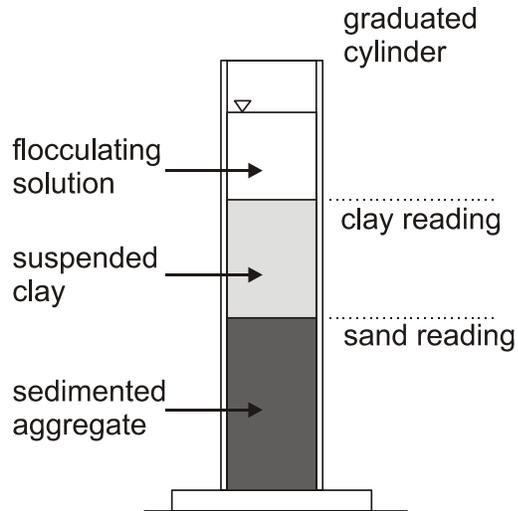


Figure 4. Prepared graduated cylinder showing where the sand and clay readings are taken.

Calculate the sand equivalent by always rounding the partial percentages to the next whole percentage. A minimum of three tests is required to be averaged. The average result is also rounded up to the next whole percentage.

The Sand Equivalent for each test is calculated using this equation:

$$SE = \frac{\text{Sand Reading}}{\text{Clay Reading}} \times 100$$

Using the data in Table 5, the SE value for the first test of the No. 10 material is calculated as:

$$\begin{aligned} SE &= \frac{3.5}{4.9} \times 100 \\ SE &= .714 \times 100 \\ SE &= 71.4 \text{ (round up to next whole value)} \\ SE &= 72 \% \end{aligned}$$

This calculation is repeated using the other data in Table 4 to get the results for the remaining two tests on the No. 10 material. The final sand equivalent value for the No. 10 material is the average of the three tests run (rounded up to the next whole percent).

$$\begin{aligned} \#10 \text{ SE value} &= \frac{72 + 75 + 73}{3} \\ &= 73.3 \text{ (round up to next whole value)} \\ &= 74 \% \end{aligned}$$

**TABLE 5. Sample Sand Equivalent test data**

	Test #1			Test #2			Test #3			Final SE Value
	Clay	Sand	SE	Clay	Sand	SE	Clay	Sand	SE	
No. 10	4.9	3.5	72	4.8	3.6	75	4.0	2.9	73	74
Nat. Sand	4.1	3.6	88	4.2	3.6	86	4.3	3.5	82	86
No. 8	4.3	4.1	96	4.5	4.2	94	4.4	4.3	98	96

The Sand Equivalent (SE) values for the natural sand and No. 8 aggregate can also be calculated from the data in Table 5. First, the SE value for each individual test is found. The three test results are averaged for each material to get the final SE value for each stockpile.

## CHAPTER 2

### Blending Aggregates

Most of the material in an asphalt concrete mixture is aggregate. The aggregate contributes strength and stability to the completed pavement. All of the aggregate sizes needed to meet specifications and produce a mixture usually cannot be found in a single material; therefore, it becomes necessary to blend different sizes and materials in the proper proportions to produce the desired gradation.

In order to accomplish this blending process correctly, it becomes extremely important that the materials to be blended are properly sampled and the gradation or sieve size is accurately determined. In addition, the aggregate properties should be determined either on each aggregate component or the total blend.

In its simplest form, a **Job-Mix Formula** consists of two major parts:

1. The Combined Gradation of the aggregates to be used in the production of the asphalt concrete mixture.
2. The Asphalt Content necessary to produce a satisfactory mix meeting all the specification requirements.

Comments on Selecting Trial Aggregate Blends in the Lab:

1. Small changes in aggregate proportions have minimal effect on mixture volumetrics.
2. Add bag-house-fines to the blends to account for plant break down during production.
3. Very coarse mixes tend to be hard to compact and may have permeability problems.
4. Very fine mixes tend to be tender during compaction and require a lot of asphalt binder.

#### **Method for Combining Aggregates:**

Sophisticated mathematical procedures have been developed that will determine an optimum combination of aggregates. Even with a calculator, however, these methods are complex and time consuming. Although these methods and formulas are available, the "trial and error method" guided by a certain amount of knowledge and experience remains one of the best, and is the easiest procedure to use to determine a satisfactory combination.

There are multiple software programs available to assist with this process. These programs will automate the mathematical calculations required to blend the individual aggregate gradations and properties.

Regardless of the number of materials combined or the method by which the proportions are determined, the basic formula is:

$$P = \left( \frac{A \times a}{100} \right) + \left( \frac{B \times b}{100} \right) + \left( \frac{C \times c}{100} \right) + \text{etc...}$$

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...
- a, b, c, etc... = The proportions of each aggregate, A, B, C, etc... used in the combination and where the total  $a+b+c+\dots = 1$

Example: Calculate the % passing the No. 8 sieve for the total aggregate blend given.

Material	No. 8's	Asphalt Sand	No. 10's	Bag House
<b>% Used</b>	<b>46 (a)</b>	<b>16 (b)</b>	<b>37 (c)</b>	<b>1 (d)</b>
Sieve Size	% Passing			
½ in. (12.5mm)	100.0	100.0	100.0	100.0
¾ in. (9.5mm)	89.8	100.0	100.0	100.0
No. 4 (4.75mm)	22.1	99.0	94.0	100.0
<b>No. 8 (2.36mm)</b>	<b>5.6 (A)</b>	<b>86.0 (B)</b>	<b>60.0 (C)</b>	<b>100.0 (D)</b>
No. 16 (1.16mm)	2.0	68.0	38.0	100.0
No. 30 (600µm)	1.8	50.0	25.0	100.0
No. 50 (300µm)	1.6	17.0	18.0	100.0
No. 100 (150µm)	1.2	4.0	12.0	100.0
No. 200 (75µm)	0.9	1.5	9.1	90.0

$$P = \left(\frac{A \times a}{100}\right) + \left(\frac{B \times b}{100}\right) + \left(\frac{C \times c}{100}\right) + \left(\frac{D \times d}{100}\right)$$

$$P = \left(\frac{5.6 \times 46}{100}\right) + \left(\frac{86.0 \times 16}{100}\right) + \left(\frac{60.0 \times 37}{100}\right) + \left(\frac{100.0 \times 1}{100}\right)$$

$$P = \left(\frac{257.6}{100}\right) + \left(\frac{1376}{100}\right) + \left(\frac{2220}{100}\right) + \left(\frac{100}{100}\right)$$

$$P = 2.576 + 13.76 + 22.2 + 1$$

$$P = 39.5$$

Thus, when the stockpiles are blended in the proportions given, the blend will have 39.5% passing the No. 8 sieve.

Here is the complete gradation blend:

Material	No. 8's		Asphalt Sand		No. 10's		Bag House		
% Used	46 %		16 %		37 %		1 %		
Sieve Size	% Pass	% Blend	% Pass	% Blend	% Pass	% Blend	% Pass	% Blend	Total Blend
½ in. (12.5mm)	100.0	46.0	100.0	16.0	100.0	37	100.0	1	<b>100.0</b>
¾ in. (9.5mm)	89.8	41.3	100.0	16.0	100.0	37	100.0	1	<b>95.3</b>
No. 4 (4.75mm)	22.1	10.2	99.0	15.8	94.0	34.8	100.0	1	<b>61.8</b>
No. 8 (2.36mm)	5.6	2.6	86.0	13.8	60.0	22.2	100.0	1	<b>39.5</b> ← (P)
No. 16 (1.16mm)	2.0	0.9	68.0	10.9	38.0	14.1	100.0	1	<b>26.9</b>
No. 30 (600µm)	1.8	0.8	50.0	8.0	25.0	9.3	100.0	1	<b>19.1</b>
No. 50 (300µm)	1.6	0.7	17.0	2.7	18.0	6.7	100.0	1	<b>11.1</b>
No. 100 (150µm)	1.2	0.6	4.0	0.6	12.0	4.4	100.0	1	<b>6.6</b>
No. 200 (75µm)	0.9	0.4	1.5	0.2	9.1	3.4	90.0	0.9	<b>4.9</b>

**Blended Aggregate Properties:**

Once the aggregate blend has been established, the mix design technician can determine the blended aggregate properties. These blended properties can be computed mathematically from the individual aggregate properties or if the technician chooses, the individual aggregates can be blended together and each property measured on the blend. Normally individual aggregate properties are measured but it is more accurate to test the blended materials.

Blending Specific Gravities and Absorption:

Formula:

$$\text{Blended } G_{xx} = \frac{P_1 + P_2 + \dots + P_n}{\left( \frac{P_1}{G_1} + \frac{P_2}{G_2} + \dots + \frac{P_n}{G_n} \right)}$$

Where:

Blended  $G_{xx}$  = specific gravity or absorption for the total blend (i.e.  $G_{sb}$ ) $P_1, P_2, \dots, P_n$  = percentage by weight of aggregates, 1, 2, ...n $G_1, G_2, \dots, G_n$  = specific gravity of aggregates (bulk or apparent), 1, 2, ...nExample: Finding  $G_{sb}$ ,  $G_{sa}$  and absorption for an aggregate blend.

Data:

Material	No. 8's	Asphalt Sand	No. 10's	Bag House
<b>% Used</b>	46 %	16 %	37 %	1 %
<b><math>G_{sb}</math></b>	2.611	2.588	2.624	2.624
<b><math>G_{sa}</math></b>	2.675	2.667	2.694	2.624
<b>Absorption, %</b>	0.91	1.13	1.00	--

a) Bulk Specific Gravity:

$$\text{Blended } G_{sb} = \frac{46 + 16 + 37 + 1}{\left( \frac{46}{2.611} + \frac{16}{2.588} + \frac{37}{2.624} + \frac{1}{2.624} \right)}$$

$$\text{Blended } G_{sb} = \frac{100}{17.618 + 6.182 + 14.101 + 0.381}$$

$$\text{Blended } G_{sb} = \frac{100}{38.282} = 2.612$$

b) Apparent Specific Gravity:

$$\text{Blended } G_{sa} = \frac{46 + 16 + 37 + 1}{\left( \frac{46}{2.675} + \frac{16}{2.667} + \frac{37}{2.694} + \frac{1}{2.624} \right)}$$

$$\text{Blended } G_{sa} = \frac{100}{17.196 + 5.999 + 13.734 + 0.381}$$

$$\text{Blended } G_{sa} = \frac{100}{37.310} = 2.680$$

c) Absorption:

$$\text{Blended Abs.} = \frac{46 + 16 + 37}{\left( \frac{46}{0.91} + \frac{16}{1.13} + \frac{37}{1.00} \right)}$$

$$\text{Blended Abs.} = \frac{99}{50.55 + 14.16 + 37}$$

$$\text{Blended Abs.} = \frac{99}{101.71}$$

$$\text{Blended Abs.} = 0.97$$

Blended Aggregate Consensus and Source Properties:

Example: Calculating Sand Equivalent (SE) and Fine Aggregate Angularity (FAA) for a blended aggregate.

Data:

Material	No. 8's	Asphalt Sand	No. 10's	Bag House
% Used	46 %	16 %	37 %	1 %
Sand Equivalent	95.0	88.0	71.0	n/a
F & E, %	3.0	n/a	n/a	n/a
FAA, %	n/a	46.1	49.0	n/a
CAA, % (1 or more)	100.0	n/a	n/a	n/a
CAA, % (2 or more)	100.0	n/a	n/a	n/a

Sand Equivalent:

*Note: If an aggregate has less than 10% passing the No. 4 (4.75mm) sieve, do not run or consider the sand equivalent value for that aggregate.*

$$\text{Blended SE} = \frac{(\text{SE}_1 \times \text{Pass No. 4}_1 \times P_1) + (\text{SE}_2 \times \text{Pass No. 4}_2 \times P_2) + \dots (\text{SE}_n \times \text{Pass No. 4}_n \times P_n)}{(\text{Pass No. 4}_1 \times P_1) + (\text{Pass No. 4}_2 \times P_2) + \dots (\text{Pass No. 4}_n \times P_n)}$$

Where:

$\text{SE}_1, \text{SE}_2, \dots \text{SE}_n$  = measured sand equivalent for aggregate 1,2,...n

$\text{PassNo.4}_1, \text{PassNo.4}_2, \text{etc.}$  = % passing No. 4 (4.75mm) sieve for aggregate 1,2,...n

$P_1, P_2, \dots P_n$  = percentage by weight of aggregate 1,2,...n

$$\text{Blended SE} = \frac{(95 \times 22.1 \times 46) + (88 \times 99 \times 16) + (71 \times 94 \times 37)}{(22.1 \times 46) + (99 \times 16) + (94 \times 37)}$$

$$\text{Blended SE} = \frac{96577 + 139392 + 246938}{1016.6 + 1584 + 3478}$$

$$\text{Blended SE} = \frac{482907}{6078.6}$$

Blended SE = 79.4 *Always round up.*

Blended SE = 80

Fine Aggregate Angularity:

Note: If <10% passing the No. 8 (2.36mm) sieve, do not run or consider the FAA value for that aggregate.

$$\text{Blended FAA} = \frac{(\text{FAA}_1 \times \text{Pass\#8}_1 \times P_1) + (\text{FAA}_2 \times \text{Pass\#8}_2 \times P_2) + \dots (\text{FAA}_n \times \text{Pass\#8}_n \times P_n)}{(\text{Pass\#8}_1 \times P_1) + (\text{Pass\#8}_2 \times P_2) + \dots (\text{Pass\#8}_n \times P_n)}$$

Where:

$\text{FAA}_1, \text{FAA}_2, \dots, \text{FAA}_n$  = measured fine aggregate angularity for aggregate 1, 2, ..., n

PassNo.8<sub>1</sub>, PassNo.8<sub>2</sub>, etc... = % passing No. 8 (2.36mm) sieve for aggregate 1, 2, ..., n

$P_1, P_2, \dots, P_n$  = percentage by weight of aggregate 1, 2, ..., n

$$\text{Blended FAA} = \frac{(46.1 \times 86.0 \times 16) + (49.0 \times 60.0 \times 37)}{(86.0 \times 16) + (60.0 \times 37)}$$

$$\text{Blended FAA} = \frac{63433.6 + 108780}{1376 + 2220}$$

$$\text{Blended FAA} = \frac{172213.6}{3596}$$

$$\text{Blended FAA} = 47.9$$

## CHAPTER 3

### Batching Specimens

The goal of batching is to closely match the laboratory aggregate blend to the final field aggregate blend. Tight control in stockpile sampling and laboratory blending procedures will help achieve a close match.<sup>1</sup> The two most common methods utilized when batching aggregates are to sieve each stockpile sample into different size fractions and recombine, or to bulk batch. With either method, proper lab procedures need to be followed to achieve an accurate blend.

Fractionating stockpile samples will add considerable time to the mix design process. Also the mix design technician needs to ensure that the stockpile sample is divided on all sieves from the top size through the pan (dust).

*Caution:* separating stockpile samples on each sieve gives the mix design technician greater control of the blended aggregate gradation than plant production is typically able to achieve.

Typically, bulk batching is used. With bulk batching, the mix design technician is trying to mimic the plant production process. Just as segregation in plant stockpiles is detrimental to the mixture, the same holds true for aggregate samples in the lab. Each stockpile sample should be placed in a large flat bottom pan and a thin flat bottom scoop used to remove the aggregate (See figures 1-3). This simulates the loader sampling from one face and always starting at the base of the stockpile. NEVER scoop from a bucket or sample bag.



Fig.1. Correct setup for bulk batching procedure.



Fig. 2. Be sure the scoop is in contact with the bottom of the pan so that a representative sample is taken. Use proper procedures to prevent segregation.



Fig. 3. Weigh all coarse materials as close as possible ( $\pm 3$  g) without segregating. Fine materials should be measured within  $\pm 1$  g.

Besides blending the individual stockpile samples that will result in the final mix design gradation, the mix design technician should try to account for aggregate breakdown in the plant mixing process. This is done by adding bag house fines to the blend. Experience is the best way to determine the amount of aggregate breakdown within a specific plant. Another option is to take a cold feed belt cut and a corresponding mixture sample and perform gradations on each for a comparison. Typical aggregate break-down runs between 1 to 2 percent.

*Caution:* If the plant uses hydrated lime as an antistripping additive, the bag house fines will also contain lime. Instead of using bag house fines to simulate aggregate break down in the plant, the technician should add 1%-2% of additional -200 material sieved from one of the aggregate stockpiles.

The amount of material needed depends on several factors including aggregate shape, aggregate specific gravity, and volume of the sample required for testing. For example, a compacted gyratory specimen should net a sample height of  $115 \pm 5$  millimeters. If the aggregate bulk specific gravity is 2.600, then approximately 4600 grams of mixture will be needed to get the specified sample height. However, an aggregate bulk specific gravity of 3.000 may require 5200 grams of mixture for the same size gyratory specimen. Experience is the best indicator for the mixture weight.

The Asphalt Institute recommends that “In the analysis of aggregates for a given mix design, the final operation is the computation of the laboratory batch weights. It is convenient to use the same weight of aggregate in each batch, in this way, the only variable is the amount of asphalt to be added.”<sup>2</sup>

**Authors Note:** By batching the same weights for all gyratory specimens, the initial weight of the mixing bowl and batched aggregate for each specimen can be checked before adding the asphalt. This weight should be consistent batch to batch.

### **Computations:**

*If the total mixture specimen weight is assumed and the percent asphalt in the specimen known, how is the amount of aggregate and asphalt determined?*

First determine the weight of asphalt and the weight of aggregate:

$$W_b = W_m \times \left( \frac{P_b}{100} \right)$$

$$W_s = W_m - W_b$$

Where,

- $W_m$  = Weight of mixture
- $W_b$  = Weight of asphalt binder
- $W_s$  = Oven-dry weight of aggregate (stone)
- $P_b$  = Percent of asphalt binder

For this example, the target is a gyratory specimen weight of 4600 grams with 6.0% asphalt.

$$\begin{aligned} \text{Asphalt Binder Weight (} W_b \text{)} &= 4600 \times \left( \frac{6.0}{100} \right) \\ &= 4600 \times 0.06 \\ &= 276\text{g} \\ &= 4600 - 276 \end{aligned}$$

$$\text{Aggregate Weight (} W_s \text{)} = 4324\text{g}$$

As stated earlier, “In the analysis of aggregates for a given mix design, the final operation is the computation of the laboratory batch weights. It is convenient to use the same weight of aggregate in each batch, in this way, the only variable is the amount of asphalt to be added.”<sup>3</sup>

With a known aggregate weight and percent asphalt, determine the asphalt weight:

First find the total specimen (mixture) weight, then determine the asphalt weight:

$$W_m = \frac{W_s}{\left[1 - \left(\frac{P_b}{100}\right)\right]}$$

$$W_b = W_m - W_s$$

Where,

$W_m$  = Weight of mixture.

$W_b$  = Weight of asphalt binder.

$W_s$  = Oven-dry weight of aggregate (stone).

$P_b$  = Percent of asphalt binder.

For this example the aggregate weight is 4324g and 6.0 percent asphalt should be added.

$$\begin{aligned} \text{Mixture Weight (} W_m \text{)} &= \frac{4324}{\left[1 - \left(\frac{6.0}{100}\right)\right]} \\ &= \frac{4324}{[1 - 0.06]} \\ &= \frac{4324}{0.94} \\ &= 4600\text{g} \\ &= 4600 - 4324 \end{aligned}$$

$$\text{Asphalt Binder Weight (} W_b \text{)} = 276\text{g}$$

With both of these calculations the goal is to obtain the specimen aggregate weight, asphalt weight, and mixture weight. These values are required to calculate the individual component percentage weights for each specimen.

To evaluate a mix design a set of three (3) gyratory specimens must be prepared at the target asphalt content, the target asphalt content  $\pm 0.5\%$ , and the target asphalt content  $\pm 1.0\%$ . Remember, each specimen is bulk batched. When bulk batching, ALWAYS include a gradation check. That is, one additional specimen is batched and a wash gradation performed to verify the specimen gradation is close to the target blend.

When batching it is important to start with the coarse aggregate and work to the fine materials. Also it is important to use cumulative weights from one stockpile to the next - this ensures the aggregate blend weight will properly correspond to the asphalt weight.

*NOTE: NEVER BATCH AND MIX A LARGER SIZE SAMPLE THAN IS TO BE TESTED. THE ENTIRE MIXTURE MUST BE EVALUATED.*

### **Calculating Individual Stockpile Weights:**

$$A = B \times \frac{C}{100}$$

Where,

- A = Weight of aggregate from an individual stockpile.
- B = Total weight of blended aggregate for gyratory specimen
- C = Percentage of stockpile needed in blend.

Example: Calculations for Gyratory Weights:

Data:

<b>Stockpiles</b>	<b>Blend %</b>
No. 8's	46
Asphalt Sand	16
# 10's	37
Bag House	1

Blended (Total) Aggregate Weight is: 4324g

a) Batch weight for No.8 stockpile:

$$\begin{aligned}
 \#8 \text{ Stockpile (A)} &= 4324 \times \frac{46}{100} \\
 &= 4324 \times 0.46 \\
 &= 1989.1 \text{ grams}
 \end{aligned}$$

b) Batch weight for asphalt sand stockpile:

$$\begin{aligned}\text{Asphalt Sand Stockpile (A)} &= 4324 \times \frac{16}{100} \\ &= 4324 \times 0.16 \\ &= 691.8 \text{ grams}\end{aligned}$$

c) Batch weight for No.10 stockpile:

$$\begin{aligned}\text{\#10 Stockpile (A)} &= 4324 \times \frac{37}{100} \\ &= 4324 \times 0.37 \\ &= 1599.9 \text{ grams}\end{aligned}$$

d) Batch weight for bag house fines:

$$\begin{aligned}\text{BH Stockpile (A)} &= 4324 \times \frac{1}{100} \\ &= 4324 \times 0.01 \\ &= 43.2 \text{ grams}\end{aligned}$$

Resulting Aggregate Batch Weights:

<b>Stockpiles</b>	<b>Blend %</b>	<b>Weights</b>	<b>Cumulative Wt.</b>
No. 8's	46	1989.1	1989.1
Asphalt Sand	16	691.8	2680.9
No. 10's	37	1599.9	4280.8
Bag House	1	43.2	4324.0

Calculate the asphalt binder weight for each asphalt percentage 5.5, 6.0, & 6.5 (see previous example).

<b>Asphalt %</b>	<b>Asphalt Weight</b>
5.5	251.7
6.0	276.0
6.5	300.6

Summary:

<b>Asphalt %</b>	<b>Asphalt Weight</b>	<b>Aggregate Weight</b>	<b>Mixture Weight</b>
5.5	251.7	4324	4575.7
6.0	276.0		4600.0
6.5	300.6		4624.6

---

<sup>1</sup> Members of the Asphalt Institute, Mix Design Methods for Asphalt Concrete (MS-2), Sixth Edition, 1994: p41.

<sup>2</sup> Members of the Asphalt Institute, Mix Design Methods for Asphalt Concrete (MS-2), Sixth Edition, 1994: p41.

<sup>3</sup> Members of the Asphalt Institute, Mix Design Methods for Asphalt Concrete (MS-2), Sixth Edition, 1994: p41.

## CHAPTER 4

### Selecting Target Gradation For Job Mix Submittal

When determining the gradation that will be submitted to the Department, there are several key elements that must be taken into account. First is knowing the history of aggregate breakdown when the material is produced at the plant, which should be accounted for in the mix design process. This is why when designing the mix baghouse fines, (typically 1.0% - 2.0%) are added to the blend.

The second consideration is when the asphalt content is determined by use of the Muffle Furnace, some aggregates tend to break down more than others. Therefore, in determining the Muffle Furnace Correction Factor it is necessary that a gradation of the material be determined so that the Mix Design technician can verify that the aggregates selected for use are not breaking down to a point that the material will not meet the target gradation that has been selected for acceptance.

When designing the mix below, the technician used the history of the plant to incorporate one percent baghouse fines into the design. This should account for the breakdown of aggregates when the mix is produced at the plant. For example, Table 1 lists the four sample gradations, in terms of percent passing that were determined when performing the Muffle Furnace Correction Factor.

**TABLE 1. Example gradations used to determine the Muffle Furnace Correction Factor**

Sieve size	% PASSING					
	Sample 1	Sample 2	Sample 3	Sample 4	Average	Target Blend
1/2	100.0	100.0	100.0	100.0	100.0	100.0
3/8	95.7	95.4	95.1	95.5	95.4	95.3
#4	63.0	63.1	62.5	63.5	63.0	61.8
#8	41.5	42.8	41.4	42.6	42.1	39.5
#16	29.4	31.1	28.8	29.6	29.7	26.9
#30	20.9	21.7	20.1	20.5	20.8	19.1
#50	11.6	11.9	11.8	12.0	11.8	11.1
#100	7.1	7.3	7.0	7.3	7.2	6.6
#200	5.1	5.4	5.2	5.3	5.3	4.9

Note: The shadowed areas in the above table are sieves that were defined as not being control sieves and are not used for acceptance.

In reviewing the gradations used for the Muffle Furnace Correction Factor and the gradation of the target blend, we can see that the average gradation from the muffle furnace is slightly finer than the target gradation. Table II-13 of the *Road and Bridge Specifications* lists the control sieves for each asphalt mix type and its design range for percent passing. Based on this information the Mix Design technician should determine the Job Mix gradation to be that given in Table 2.

**TABLE 2. Job mix gradation for the sample**

<b>Job-Mix Sieves</b>	<b>Total Percent Passing</b>
1/2	100
3/8	95
#4	63
#8	42
#200	5.3

Now that a determination has been made as to what the target will be for acceptance, the next step is to determine the acceptance ranges for the mix. Section 211 Table II-15 of the *Road and Bridge Specifications* denotes the process tolerance on each laboratory sieve. Using the target determined for each sieve and Table II-15 we can determine the acceptance range for the mix as given in Table 3.

**TABLE 3. Job mix gradation acceptance ranges for the sample**

<b>Job-Mix Sieves</b>	<b>Total Percent Passing</b>	<b>Tolerance in Percent</b>	<b>Acceptance Range Average of 4 Tests</b>
1/2	100	0*	100
3/8	95	4	91-99
#4	63	4	59-67
#8	42	4	38-46
#200	5.3	1	4.3-6.3

Note: The information listed above will need to be reported on the TL-127 form.

\* For SM-9.0 and SM-9.5 mixes, there will be a 1% tolerance applied to the Top Sieve Size. This tolerance was introduced due to oversize material being incorporated into the mix due to processing of RAP.

## CHAPTER 5

### Selecting the Design Asphalt Content

Once the design aggregate structure is selected, specimens are compacted at three different asphalt contents. The mixture properties are then evaluated to determine the design asphalt content. A minimum of three specimens are compacted at each of the three asphalt contents selected:

- Estimated asphalt content
- 0.5% below estimated asphalt content
- 0.5% above estimated asphalt content

When making the selection for the estimated asphalt content the mix design technician should take into account the plant history for this type of mix. The selected asphalt content should be very close to the 4.0% VTM design criteria.

For this example the mix design technician has decided to use 5.9% for the estimated asphalt content. This means that he/she will be required to compact three specimens at an asphalt content of 5.4%, three specimens at an asphalt content of 5.9% and three specimens at an asphalt content of 6.4%. A butter batch is required prior to mixing the samples. If the mixer is cleaned after each varying asphalt content, then a butter batch will be required for each varying asphalt content. Specimens are prepared and tested in the same manner as the specimens from the "Selection of A Design Aggregate Structure" in the FHWA workbook. A minimum of two additional samples is required for determining the maximum theoretical specific gravity for each asphalt content.

Note: AASHTO PP-28 sec. 8.4 Note 8 requires 2 tests to be performed for Maximum Theoretical Specific Gravity. Sample size shall be in accordance to AASHTO T-209.

## **Blending**

Based on the volumetric data from the aggregate trial blends the mix design technician has decided to use 46% #8's, 16% sand, 37% #10's and 1% bag house fines. The 1% bag house fines is to account for plant breakdown of aggregates. The amount of bag house fines used in the mix design is based on the plant history for aggregate breakdown when HMA is produced through the plant. Table 1 is an example of how to batch the material for mixing:

**Table – 1. Sample asphalt content and aggregate blends**

	<b>% blend #1</b>	<b>% blend #2</b>	<b>% blend #3</b>
<b>Asphalt content</b>	5.4	5.9	6.4
<b>Aggregates</b>			
#8	46	46	46
Sand	16	16	16
#10	38	38	38
bag house fines	1	1	1

**Gyratory Pill Mass: = 4600 grams (the pill mass used is based on the aggregate blend section).**

**Mass needed to determine the Maximum Theoretical Specific Gravity: = 2000 grams.**

▪ **1<sup>st</sup> Asphalt Blend (*Pills*) at estimated Asphalt Content of 5.9%**

Using the data from Table 1 determine the batch mass required for the gyratory pills to yield approximately 4600 grams at the estimated asphalt content:

1) Determine the mass of asphalt needed in grams:

$$\frac{(A \times B)}{100} = \text{Asphalt needed in grams ( } C \text{ )}$$

Where,

$A$  = Batch mass for pills

$B$  = % Asphalt

$$\frac{(4600 \times 5.9)}{100} =$$

$$\frac{27140}{100} =$$

$$271.4 = \text{Asphalt needed in grams ( } C \text{ )}$$

2) Determine the mass of aggregates needed:

$$A - C = \text{Aggregates needed in grams ( } D \text{ )}$$

Where,

$A$  = Batch mass for pills

$C$  = Asphalt needed in grams

$$4600 - 271.4 = 4328.6 \text{ Aggregates needed in grams ( } D \text{ )}$$

3) Determine the mass for each aggregate used in blend:

a) #8 stone - 46% of blend:

$$\frac{(D \times E)}{100} = \text{\#8 stone needed in grams}$$

Where,

$D$  = Aggregates needed in grams

$E$  = % of aggregate type used for blend

$$\frac{(4328.6 \times 46)}{100} =$$

$$\frac{199115.6}{100} = 1991.2 \text{ \#8 stone needed in grams}$$

b) Sand – 16% of blend:

$$\frac{(D \times E)}{100} = \text{Sand needed in grams}$$

Where,

$D$  = Aggregates needed in grams

$E$  = % of aggregate type used for blend

$$\frac{(4328.6 \times 16)}{100} =$$

$$\frac{69257.6}{100} =$$

$$692.6 = \text{Sand needed in grams}$$

c) #10 Stone – 37% of blend:

$$\frac{(D \times E)}{100} = \text{\#10 stone needed in grams}$$

Where,

$D$  = Aggregates needed in grams

$E$  = % of aggregate type used for blend

$$\frac{(4328.6 \times 37)}{100} =$$

$$\frac{160158.2}{100} =$$

$$1601.6 = \text{\#10 stone needed in grams}$$

d) Bag house fines – 1% of blend

$$\frac{(D \times E)}{100} = \text{Bag house fines needed in grams}$$

Where,

$D$  = Aggregates needed in grams

$E$  = % of aggregate type used for blend

$$\frac{(4328.6 \times 1)}{100} =$$

$$\frac{4328.6}{100} = 43.3 \text{ Bag house fines needed in grams}$$

▪ **1<sup>st</sup> Asphalt Blend ( $G_{mm}$ ) at estimated Asphalt Content of 5.9%**

Using the information from Table 1 determine the batch mass required for the Maximum Theoretical Specific Gravity (Rice) test that will yield approximately 2000 grams at the estimated asphalt content:

1) Determine the mass of asphalt needed in grams:

$$\frac{(A \times B)}{100} = \text{Asphalt needed in grams (C)}$$

Where,

$$\begin{aligned} A &= \text{Batch mass for } G_{mm} \\ B &= \% \text{ Asphalt} \end{aligned}$$

$$\frac{(2000 \times 5.9)}{100} =$$

$$\frac{11800}{100} = 118.0 \text{ Asphalt needed in grams (C)}$$

2) Determine the mass of aggregates needed:

$$A - C = \text{Aggregates needed in grams (D)}$$

Where,

$$\begin{aligned} A &= \text{Batch mass for } G_{mm} \\ C &= \text{Asphalt needed in grams} \end{aligned}$$

$$2000 - 118.0 = 1882.0 \text{ Aggregates needed in grams (D)}$$

3) Determine the mass for each aggregate used in blend:

a) #8 stone - 46% of blend:

$$\frac{(D \times E)}{100} = \text{\#8 stone needed in grams}$$

Where,

$$\begin{aligned} D &= \text{Aggregates needed in grams} \\ E &= \% \text{ of aggregate type used for blend} \end{aligned}$$

$$\frac{(1882 \times 46)}{100} =$$

$$\frac{86572}{100} = 865.7 \text{ \#8 stone needed in grams}$$

b) Sand – 16% of blend:

$$\frac{(D \times E)}{100} = \text{Sand needed in grams}$$

Where,

$D$  = Aggregates needed in grams

$E$  = % of aggregate type used for blend

$$\frac{(1882 \times 16)}{100} =$$

$$\frac{30112}{100} = 301.1 \text{ Sand needed in grams}$$

c) #10 Stone – 37% of blend:

$$\frac{(D \times E)}{100} = \text{\#10 stone needed in grams}$$

Where,

$D$  = Aggregates needed in grams

$E$  = % of aggregate type used for blend

$$\frac{(1882 \times 37)}{100} =$$

$$\frac{69634}{100} = 696.3 \text{ \#10 stone needed in grams}$$

d) Bag house fines – 1% of blend

$$\frac{(D \times E)}{100} = \text{Bag house fines needed in grams}$$

Where,

$D$  = Aggregates needed in grams

$E$  = % of aggregate type used for blend

$$\frac{(1882 \times 1)}{100} =$$

$$\frac{1882}{100} = 18.8 \text{ Bag house fines needed in grams}$$

Note: AASHTO PP-28 sec. 8.4 Note 8 requires 2 tests to be performed for Maximum Theoretical Specific Gravity. Sample size shall be in accordance to AASHTO T-209.

To ensure that no math errors have occurred, it is highly recommended that after calculating the mass needed for the gyratory pills and Maximum Theoretical Specific Gravity test that the mix design technician sum the total mass needed for each component and compare the sum to the original mass specified. The following shows how to perform this calculation:

#### Gyratory Pill Mass for 5.9% AC:

Aggregates	Mass in grams
#8	1991.2
Sand	692.6
#10	1601.6
Bag house fines	43.3
Liquid Asphalt	271.4
<b>Total</b>	<b>*4600.1</b>

*\* The sum of mass needed in grams should be very close to the pill mass that was originally selected. The pill mass is selected based on the amount of aggregate and asphalt needed to yield a compacted gyratory pill height of 115 mm. Experience is the best guide. Some mixes may require pill masses of 4700 grams or higher to meet the height requirement.*

#### Maximum Theoretical Specific Gravity Mass for 5.9% AC:

Aggregates	Mass in grams
#8	865.7
Sand	301.1
#10	696.3
Bag house fines	18.8
Liquid Asphalt	118
<b>Total</b>	<b>*1999.9</b>

*\* The sum of mass needed in grams should be very close to the Maximum Theoretical Specific Gravity mass that was originally specified.*

#### ▪ 2<sup>nd</sup> Asphalt Blend (Pills) at 0.5% below estimated Asphalt Content (5.4% AC)

It is now necessary to determine the batch mass required for the pills at 0.5% below the estimated asphalt content:

1) Determine the mass of asphalt needed in grams:

$$\frac{(A \times B)}{100} = \text{Asphalt needed in grams (C)}$$

Where,

A = Batch mass  
B = % Asphalt

$$\frac{(4600 \times 5.4)}{100} =$$

$$\frac{24840}{100} = 248.4 \text{ Asphalt needed in grams (C)}$$

- 2) The mass of aggregate needed is the same as determined in the first blend at 5.9% asphalt. The only change is the amount of asphalt needed to produce approximately 5.4% asphalt content. This process is called bulk batching. The goal in bulk batching is to keep the aggregate structure constant and vary the asphalt content. The total pill mass will be slightly less than 4600 grams.

**Pill Mass for 5.4% AC:**

Aggregates	Mass in grams
#8	1991.2
Sand	692.6
#10	1601.6
Bag house fines	43.3
<b>Liquid Asphalt</b>	248.4
<b>Total</b>	<b>4577.1</b>

- **2<sup>nd</sup> Asphalt Blend ( $G_{mm}$ ) at 0.5% below the estimated Asphalt Content (5.4% AC)**

Similarly, it is necessary to determine the batch mass required for the Maximum Theoretical Specific Gravity (Rice) at 0.5% below the estimated asphalt content:

- 1) Determine the mass of asphalt needed in grams:

$$\frac{(A \times B)}{100} = \text{Asphalt needed in grams } (C)$$

Where,

$A$  = Batch mass for  $G_{mm}$

$B$  = % Asphalt

$$\frac{(2000 \times 5.4)}{100} =$$

$$\frac{10800}{100} = 108.0 \text{ Asphalt needed in grams } (C)$$

3) The mass of aggregate needed is the same as determined in the first blend at 5.9% asphalt the only change is the amount of asphalt needed to produce approximately 5.4%. This process is called bulk batching. The goal in bulk batching is to keep the aggregate structure constant and vary the asphalt content. The total pill mass will be slightly less than 2000 grams.

**Maximum Theoretical Specific Gravity Mass for 5.4% AC:**

Aggregates	Mass in grams
#8	865.7
Sand	301.1
#10	696.3
Bag house fines	18.8
<b>Liquid Asphalt</b>	108.0
<b>Total</b>	<b>1989.9</b>

The actual asphalt content is now 5.43%, which is slightly more than the target 5.4%.

Note: AASHTO PP-28 sec. 8.4 Note 8 requires 2 tests to be performed for Maximum Theoretical Specific Gravity. Sample size shall be in accordance to AASHTO T-209

▪ **3<sup>rd</sup> Asphalt Blend (Pills) at 0.5% above the estimated Asphalt Content (6.4% AC)**

Next determine the batch mass required for the pills at 0.5% above the estimated asphalt content:

1) Determine the mass of asphalt needed in grams:

$$\frac{(A \times B)}{100} = \text{Asphalt needed in grams (C)}$$

Where,

$A$  = Batch mass

$B$  = % Asphalt

$$\frac{(4600 \times 6.4)}{100} =$$

$$\frac{29440}{100} =$$

$$294.4 = \text{Asphalt needed in grams (C)}$$

- 2) The mass of aggregate needed is the same as determined in the first blend at 5.9% asphalt the only change is the amount of asphalt needed to produce approximately 6.4%. This process is called bulk batching. The goal in bulk batching is to keep the aggregate structure constant and vary the asphalt content. The total pill mass will be slightly less than 4600 grams.

**Pill Mass for 6.4% AC:**

Aggregates	Mass in grams
#8	1991.2
Sand	692.6
#10	1601.6
Bag house fines	43.3
<b>Liquid Asphalt</b>	294.4
<b>Total</b>	<b>4623.1</b>

▪ **3<sup>rd</sup> Asphalt Blend (G<sub>mm</sub>) 6.4% Asphalt**

Now determine the batch mass required for the Maximum Theoretical Specific Gravity (Rice) at 0.5% above the estimated asphalt content:

- 1) Determine the mass of asphalt needed in grams:

$$\frac{(A \times B)}{100} = \text{Asphalt needed in grams } (C)$$

Where,

$A$  = Maximum Theoretical Specific Gravity mass

$B$  = % Asphalt

$$\frac{(2000 \times 6.4)}{100} =$$

$$\frac{12800}{100} = 128.0 = \text{Asphalt needed in grams } (C)$$

- 2) The mass of aggregate needed is the same as determined in the first blend at 5.9% asphalt the only change is the amount of asphalt needed to produce approximately 6.4%. This process is called bulk batching. The goal in bulk batching is to keep the aggregate structure constant and vary the asphalt content.

The total pill mass will be slightly more than the 2000 grams needed:

**Maximum Theoretical Specific Gravity Mass for 6.4% AC:**

<b>Aggregates</b>	<b>Mass in grams</b>
#8	865.7
Sand	301.1
#10	696.3
Bag house fines	18.8
<b>Liquid Asphalt</b>	128.0
<b>Total</b>	<b>2009.9</b>

The actual asphalt content is 6.37 %, which is slightly less than the target 6.4%.

Note: AASHTO PP-28 sec. 8.4 Note 8 requires 2 tests to be performed for Maximum Theoretical Specific Gravity. Sample size shall be in accordance to AASHTO T-209.

Once the masses have been determined for each aggregate it is now time to batch the material for testing. It is recommended that for batching materials the mix design technician weigh the finer material first then proceed with the coarser material. The reason for this approach is that specifications require a forced air oven for heating the material for mixing and compaction. If the finer material is on top, it will tend to get blown out of the pan. As always, when batching aggregates, a flat bottom scoop is required.

The mix that is being designed is a SM-9.5A so the type of PG binder to be used is PG64-22. To determine the binder grade to use for a designated mix refer to section 211.01 of the *Road and Bridge Specifications*.

Now that the material has been batched and the binder selected it is now time to heat the aggregates, binder and mixing equipment to the proper mixing temperature. In section 211.03(d) 6 of the *Road and Bridge Specifications* the proper mixing and compaction temperatures can be found for each grade type of binder.

The mix that is being designed is an SM-9.5A and the mixing temperature is 300° F to 310° F. Set the oven to the proper mixing temperature and place the aggregates, binder and mixing equipment into the oven. A dial thermometer with a range of 50° F to 400° F should be placed in each pan of material and in the binder to ensure that the material has achieved the proper mixing temperature.

Once the material has reached the specified mixing temperature proceed with combining the aggregates and liquid asphalt (*remember that the first sample to be mixed is the butter batch*). Charge the mixing bowl with the heated aggregate and mix thoroughly. Form a crater in the dry blended aggregate, and weigh the required amount of binder into the mix. Immediately initiate mixing. AASHTO R35-04 does allow the material to be mixed using a mechanical mixer or hand mixing. Whichever method of mixing is used, mixing must be uniform and with minimal loss of temperature.

After mixing, the materials must go thru an aging period. AASHTO R30-02 section 7.1.2 states that the material must be aged at the specified compaction temperature for 2 hours  $\pm$  5 minutes. The compaction temperature for this mix (refer to section 211.03(d) 6 of the *Road and Bridge Specifications*) is 285° F to 290° F.

After the material has aged, the next step is to compact the specimen in the Gyratory compactor (AASHTO T312-01). The mix design technician will need to record the height at  $N_{initial}$  and  $N_{design}$  for each specimen, and then determine the average height at  $N_{initial}$  and  $N_{design}$  for each asphalt blend. Allow the compacted specimens to cool to room temperature (16 Hours) before proceeding with the Bulk Specific Gravity (AASHTO T166-00) test.

Now that the mix design technician has performed the Maximum Theoretical Specific Gravity (AASHTO T209-99) and Bulk Specific Gravity (AASHTO T166-00), determine the  $G_{mm}$  and  $G_{mb}$  of each asphalt blend.

- **1<sup>st</sup> Asphalt Blend @ 5.9% Asphalt**

**Maximum Theoretical Specific Gravity ( $G_{mm}$ ):**

$$\frac{A}{(A - B)} = G_{mm}$$

Where,

$A$  = Sample mass in air  
 $B$  = Sample mass in water

Note: When performing this test the mix design technician must record the bucket mass in air and the bucket mass in water. When using this formula you must subtract the bucket mass from the sample so that the sample mass is used in the calculation.

### 1<sup>st</sup> Sample: Determine $G_{mm}$

(All weights in grams)

Data:	Wt. Of bucket in air	=	2350.2
	Wt. Bucket + sample in air	=	4315.5
	Wt. Bucket + sample in water	=	2640.9
	Wt. Bucket in water	=	1487.6

$$\begin{aligned} \text{Sample mass in air (A)} &= 4315.5 - 2350.2 \\ A &= 1965.3 \text{ grams} \end{aligned}$$

$$\begin{aligned} \text{Sample mass in water (B)} &= 2640.9 - 1487.6 \\ B &= 1153.3 \end{aligned}$$

$$G_{mm} = \frac{1965.3}{(1965.3 - 1153.3)}$$

$$G_{mm} = 2.420$$

### 2<sup>nd</sup> Sample: Determine $G_{mm}$ :

Data:	Wt. Of bucket in air	=	2375.5
	Wt. Bucket + sample in air	=	4356.2
	Wt. Bucket + sample in water	=	2649.9
	Wt. Bucket in water	=	1487.6

$$\begin{aligned} \text{Sample mass in air (A)} &= 4356.2 - 2375.5 \\ A &= 1980.7 \text{ grams} \end{aligned}$$

$$\begin{aligned} \text{Sample mass in water (B)} &= 2649.9 - 1487.6 \\ B &= 1162.3 \end{aligned}$$

$$G_{mm} = \frac{1980.7}{(1980.7 - 1162.3)} = 2.420$$

$$\text{Average } G_{mm} \text{ of two tests} = 2.420$$

**Bulk Specific Gravity ( $G_{mb}$ ) =**

$$\frac{A}{(B - C)} = G_{mb}$$

Where,

- $A$  = Mass in air  
 $B$  = Mass saturated surface dry  
 $C$  = Mass in water

**1<sup>st</sup> Sample:**

$$\frac{A}{(B - C)} = G_{mb}$$

$$\frac{4593.4}{(4596.9 - 2617.9)} =$$

$$\frac{4593.4}{1979.0} = 2.321 = G_{mb}$$

**2<sup>nd</sup> Sample:**

$$\frac{A}{(B - C)} = G_{mb}$$

$$\frac{4596.2}{(4598.3 - 2619.1)} =$$

$$\frac{4596.2}{1979.2} = 2.322 = G_{mb}$$

**3<sup>rd</sup> Sample:**

$$\frac{A}{(B - C)} = G_{mb}$$

$$\frac{4595.7}{(4598.9 - 2607.7)} =$$

$$\frac{4595.7}{1991.2} = 2.308 = G_{mb}$$

**Average  $G_{mb}$  of three samples = 2.317**

**Average Heights**

Asphalt content	$N_{initial}$	$N_{design}$
5.90%	127.2	117.6

- **2<sup>nd</sup> Asphalt Blend @ 5.4% Asphalt**

**Maximum Theoretical Specific Gravity ( $G_{mm}$ ):**

$$\frac{A}{(A - B)} = G_{mm}$$

Where,

$$\begin{aligned} A &= \text{Sample mass in air} \\ B &= \text{Sample mass in water} \end{aligned}$$

Note: When performing this test the mix design technician must record the bucket mass in air and in water. When using this formula you must subtract the bucket mass from the sample so that the sample mass is used in the calculation

**1<sup>st</sup> Sample:** 
$$\frac{A}{(A - B)} = G_{mm}$$

$$\frac{1950.0}{(1950.0 - 1148.2)} =$$

$$\frac{1950.0}{801.8} = 2.432 = G_{mm}$$

**2<sup>nd</sup> Sample:** 
$$\frac{A}{(A - B)} = G_{mm}$$

$$\frac{1960.4}{(1960.4 - 1155.5)} =$$

$$\frac{1960.4}{804.9} = 2.436 = G_{mm}$$

**Average  $G_{mm}$  of two tests = 2.434**

**Bulk Specific Gravity ( $G_{mb}$ ) =**

$$\frac{A}{(B - C)} = G_{mb}$$

Where,

- $A$  = Mass in air  
 $B$  = Mass saturated surface dry  
 $C$  = Mass in water

**1<sup>st</sup> Sample:**

$$\frac{A}{(B - C)} = G_{mb}$$

$$\frac{4598.2}{(4605.8 - 2599.2)} =$$

$$\frac{4598.2}{2006.6} = 2.292 = G_{mb}$$

**2<sup>nd</sup> Sample:**

$$\frac{A}{(B - C)} = G_{mb}$$

$$\frac{4580.6}{(4588.6 - 2597.1)} =$$

$$\frac{4580.6}{1991.5} = 2.300 = G_{mb}$$

**3<sup>rd</sup> Sample:**

$$\frac{A}{(B - C)} = G_{mb}$$

$$\frac{4592.8}{(4599.4 - 2595.8)} =$$

$$\frac{4592.8}{2003.6} = 2.292 = G_{mb}$$

**Average  $G_{mb}$  of three samples = 2.295**

**Average Heights**

Asphalt content	$N_{initial}$	$N_{design}$
5.43%	126.1	116.3

- **3<sup>rd</sup> Asphalt Blend @ 6.4% Asphalt**

**Maximum Theoretical Specific Gravity ( $G_{mm}$ ):**

$$\frac{A}{(A - B)} = G_{mm}$$

Where,

$$\begin{aligned} A &= \text{Sample mass in air} \\ B &= \text{Sample mass in water} \end{aligned}$$

Note: When performing this test the mix design technician must record the bucket mass in air and in water. When using this formula you must subtract the bucket mass from the sample so that the sample mass is used in the calculation

**1<sup>st</sup> Sample:** 
$$\frac{A}{(A - B)} = G_{mm}$$

$$\frac{1991.6}{(1991.6 - 1161.4)} =$$

$$\frac{1991.6}{830.2} = 2.399 = G_{mm}$$

**2<sup>nd</sup> Sample:** 
$$\frac{A}{(A - B)} = G_{mm}$$

$$\frac{1988.7}{(1988.7 - 1159.4)} =$$

$$\frac{1988.7}{829.3} = 2.398 = G_{mm}$$

**Average  $G_{mm}$  of two tests = 2.399**

**Bulk Specific Gravity ( $G_{mb}$ ) =**

$$\frac{A}{(B - C)} = G_{mb}$$

Where,

- $A$  = Mass in air  
 $B$  = Mass saturated surface dry  
 $C$  = Mass in water

**1<sup>st</sup> Sample:**

$$\frac{A}{(B - C)} = G_{mb}$$

$$\frac{4597.8}{(4600.8 - 2632.6)} =$$

$$\frac{4597.8}{1968.2} = 2.336 = G_{mb}$$

**2<sup>nd</sup> Sample**

$$\frac{A}{(B - C)} = G_{mb}$$

$$\frac{4592.1}{(4593.6 - 2623.6)} =$$

$$\frac{4592.1}{1970.0} = 2.331 = G_{mb}$$

**3<sup>rd</sup> Sample:**

$$\frac{A}{(B - C)} = G_{mb}$$

$$\frac{4593.4}{(4595.8 - 2625.2)} =$$

$$\frac{4593.4}{1970.6} = 2.331 = G_{mb}$$

**Average  $G_{mb}$  of three samples = 2.333**

**Average Heights**

Asphalt content	$N_{initial}$	$N_{design}$
6.37%	125.9	117.8

After the calculating Maximum Theoretical Specific Gravity and Bulk Specific Gravity the next step is to calculate the volumetrics and F/A ratio. Once this has been done an evaluation is made to determine which asphalt content is to be used for the job mix submittal.

**Table 2**

Asphalt content	$G_{mm}$	$G_{mb}$
5.43%	2.434	2.295
5.90%	2.420	2.317
6.37%	2.399	2.333

**Table 3**

Asphalt content	$N_{initial}$	$N_{design}$
5.43%	126.1	116.3
5.90%	127.2	117.6
6.37%	125.9	117.8

Note: Average heights at  $N_{initial}$  and  $N_{design}$  are needed to ensure that the specimens were compacted within the specified height requirement and for determining the density at  $N_{initial}$ .

- **1<sup>st</sup> asphalt blend (5.9%)**

Using the information from Table 2, determine  $VTM$ ,  $VMA$  and  $VFA$  of the mix:

**1) Determine  $VTM$  :**

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

Where,

$G_{mb}$  = Bulk Specific Gravity of mix

$G_{mm}$  = Maximum Theoretical Specific Gravity of mix

$$100 \times \left[ 1 - \left( \frac{2.317}{2.420} \right) \right] =$$

$$100 \times [1 - .957] =$$

$$100 \times .043 = 4.3 = VTM$$

2) **Determine VMA :**

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

Where,

- $G_{mb}$  = Bulk Specific Gravity of mix  
 $P_s$  = Percent stone (100 - % asphalt)  
 $G_{sb}$  = Bulk Specific Gravity of combined aggregate (Determined in aggregate blend)

$$100 \times \left( 1 - \frac{2.317(100 - 5.9)}{2.612} \right) =$$

$$100 \times \left( 1 - \frac{2.317(94.1)}{2.612} \right) \text{ (* \% stone must be converted to a decimal by } \frac{94.1}{100} \text{.)}$$

$$100 \times \left( 1 - \frac{2.317(94.1)}{2.612} \right) =$$

$$100 \times \left( 1 - \frac{2.180}{2.612} \right) =$$

$$100 \times (1 - .835) =$$

$$100 \times .165 = 16.5 = VMA$$

3) **Determine VFA :**

$$100 \times \left( \frac{VMA - VTM}{VMA} \right) = VFA$$

Where,

- $VMA$  = Voids in Mineral Aggregate  
 $VTM$  = Voids in Total Mix

$$100 \times \left( \frac{16.5 - 4.3}{16.5} \right) =$$

$$100 \times \left( \frac{12.2}{16.5} \right) =$$

$$100 \times .739 = 73.9 = VFA$$

4) **Determine %  $G_{mm}$  at  $N_{initial}$  :**

$$100 \times \left( \frac{G_{mb}(h_d)}{G_{mm}(h_i)} \right) = \% G_{mm} \text{ at } N_{initial}$$

Where,

- $G_{mb}$  = Bulk Specific Gravity of mix
- $G_{mm}$  = Maximum Theoretical Specific Gravity of mix
- $h_d$  = Height at  $N_{design}$
- $h_i$  = Height at  $N_{initial}$

$$100 \times \left( \frac{2.317(117.6)}{2.420(127.2)} \right) =$$

$$100 \times \left( \frac{272.48}{307.82} \right) =$$

$$100 \times .8852 = 88.5 = \% G_{mm} \text{ at } N_{initial}$$

- 5) For calculating F/A you will need to determine two items. First, is the percent passing the 200 sieve, which can be acquired from the aggregate blending data. Second, is the percent of effective binder ( $P_{be}$ ), which is the amount of binder that is not absorbed in the aggregate.

$$P_b - \left[ (P_s \times G_b) \left( \frac{G_{se} - G_{sb}}{G_{se} \times G_{sb}} \right) \right] = P_{be}$$

Where,

- $P_b$  = Percent binder
- $P_s$  = Percent stone
- $G_b$  = Specific gravity of binder
- $G_{se}$  = Effective specific gravity of combined aggregate
- $G_{sb}$  = Specific gravity of combined aggregate

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

Where,

- $P_b$  = Percent binder  
 $G_{mm}$  = Maximum Theoretical Specific Gravity of mix  
 $G_b$  = Specific gravity of binder

$$\frac{(100 - 5.9)}{\frac{100}{2.420} - \frac{5.9}{1.032}} = G_{se}$$

$$\frac{94.1}{41.32 - 5.72} = G_{se}$$

$$\frac{94.1}{35.60} = 2.643 = G_{se}$$

$$5.90 - \left[ (94.1 \times 1.032) \frac{(2.643 - 2.612)}{(2.643 \times 2.612)} \right] = P_{be}$$

$$5.90 - \left[ (97.11) \frac{.031}{6.904} \right] = P_{be}$$

$$5.90 - [(97.11).0045] = P_{be}$$

$$5.90 - .44 = 5.46 = P_{be}$$

Using the information above and the percent passing the 200 sieve (aggregate blend sheet) calculate the F/A ratio:

$$\frac{P_{.075}}{P_{be}} = \text{F/A ratio}$$

Where,

- $P_{.075}$  = Percent passing 200 sieve  
 $P_{be}$  = Percent effective binder

$$\frac{4.9}{5.46} = .897 = 0.9 = \text{F/A ratio}$$

- **2<sup>nd</sup> asphalt blend (5.4%)**

Using the information from Table 2, determine the *VTM*, *VMA* and *VFA* of the mix:

**1) Determine *VTM* :**

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

Where,

$G_{mb}$  = Bulk Specific Gravity of mix

$G_{mm}$  = Maximum Theoretical Specific Gravity of mix

$$100 \times \left[ 1 - \left( \frac{2.295}{2.434} \right) \right] =$$

$$100 \times [1 - .943] =$$

$$100 \times .057 = 5.7 = VTM$$

**2) Determine *VMA* :**

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

Where,

$G_{mb}$  = Bulk Specific Gravity of mix

$P_s$  = Percent stone (100 - % asphalt)

$G_{sb}$  = Bulk Specific Gravity of combined aggregate (Determined in aggregate blend)

$$100 \times \left( 1 - \frac{2.295(100 - 5.43)}{2.612} \right)$$

$$100 \times \left( 1 - \frac{2.295(94.6)}{2.612} \right) \text{ (* \% stone must be converted to a decimal by } \frac{94.6}{100} \text{.)}$$

$$100 \times \left( 1 - \frac{2.295(.946)}{2.612} \right) =$$

$$100 \times \left( 1 - \frac{2.171}{2.612} \right) =$$

$$100 \times (1 - .831) =$$

$$100 \times .169 = 16.9 = VMA$$

**3) Determine VFA:**

$$100 \times \left( \frac{VMA - VTM}{VMA} \right) = VFA$$

Where,

$VMA$  = Voids in Mineral Aggregate

$VTM$  = Voids in Total Mix

$$100 \times \left( \frac{16.9 - 5.7}{16.9} \right) =$$

$$100 \times \left( \frac{11.2}{16.9} \right) =$$

$$100 \times .6627 = 6.3 = VFA$$

**4) Determine %  $G_{mm}$  at  $N_{initial}$ :**

$$100 \times \left( \frac{G_{mb}(h_d)}{G_{mm}(h_i)} \right) = \% G_{mm} \text{ at } N_{initial}$$

Where,

$G_{mb}$  = Bulk Specific Gravity of mix

$G_{mm}$  = Maximum Theoretical Specific Gravity of mix

$h_d$  = Height at  $N_{design}$

$h_i$  = Height at  $N_{initial}$

$$100 \times \left( \frac{2.295(116.3)}{2.434(126.1)} \right) =$$

$$100 \times \left( \frac{266.91}{306.93} \right) =$$

$$100 \times .8696 = 87.0 = \% G_{mm} \text{ at } N_{initial}$$

- 5) For calculating F/A you will need to determine two items. First, is the percent passing the 200 sieve, which can be acquired from the aggregate blending data. Second, is the percent of effective binder ( $P_{be}$ ), which is the amount of binder that is not absorbed in the aggregate.

$$P_b - \left[ (P_s \times G_b) \frac{(G_{se} - G_{sb})}{(G_{se} \times G_{sb})} \right] = P_{be}$$

Where,

- $P_b$  = Percent binder  
 $P_s$  = Percent stone  
 $G_b$  = Specific gravity of binder  
 $G_{se}$  = Effective specific gravity of combined aggregate  
 $G_{sb}$  = Specific gravity of combined aggregate

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

Where,

- $P_b$  = Percent binder  
 $G_{mm}$  = Maximum Theoretical Specific Gravity of mix  
 $G_b$  = Specific gravity of binder

$$\frac{(100 - 5.43)}{\frac{100}{2.434} - \frac{5.43}{1.032}} = G_{se}$$

$$\frac{94.57}{41.08 - 5.26} = G_{se}$$

$$\frac{94.57}{35.82} = 2.640 = G_{se}$$

$$5.43 - \left[ (94.57 \times 1.032) \frac{(2.640 - 2.612)}{(2.640 \times 2.612)} \right] = P_{be}$$

$$5.43 - \left[ (97.60) \frac{.028}{6.896} \right] = P_{be}$$

$$5.43 - [(97.60).0041] = P_{be}$$

$$5.43 - .40 = 5.03 = P_{be}$$

Using the information above and the percent passing the 200 sieve (aggregate blend sheet) calculate the F/A ratio:

$$\frac{P_{.075}}{P_{be}} = \text{F/A ratio}$$

Where,

$$P_{.075} = \text{Percent passing 200 sieve}$$

$$P_{be} = \text{Percent effective binder}$$

$$\frac{4.9}{5.03} = .974 = 1.0 = \text{F/A ratio}$$

- **3<sup>rd</sup> asphalt blend (6.4%)**

Using the information from Table 2, determine the *VTM*, *VMA* and *VFA* of the mix:

**1) Determine *VTM* :**

$$100 \times \left[ 1 - \left( \frac{G_{mb}}{G_{mm}} \right) \right] = \text{VTM}$$

Where,

$$G_{mb} = \text{Bulk Specific Gravity of mix}$$

$$G_{mm} = \text{Maximum Theoretical Specific Gravity of mix}$$

$$100 \times \left[ 1 - \left( \frac{2.333}{2.399} \right) \right] =$$

$$100 \times [1 - .972] =$$

$$100 \times .028 = 2.8 = \text{VTM}$$

**2) Determine VMA :**

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

Where,

- $G_{mb}$  = Bulk Specific Gravity of mix  
 $P_s$  = Percent stone (100 – % asphalt)  
 $G_{sb}$  = Bulk Specific Gravity of combined aggregate (Determined in aggregate blend)

$$100 \times \left( 1 - \frac{2.333(100 - 6.37)}{2.612} \right)$$

$$100 \times \left( 1 - \frac{2.333(93.63)}{2.612} \right) \left( \begin{array}{l} * \% \text{ stone must be converted to} \\ \text{a decimal by } \frac{93.6}{100} \end{array} \right)$$

$$100 \times \left( 1 - \frac{2.333(93.6)}{2.612} \right) =$$

$$100 \times \left( 1 - \frac{2.184}{2.612} \right) =$$

$$100 \times (1 - .836) =$$

$$100 \times .164 = 16.4 = VMA$$

**3) Determine VFA :**

$$100 \times \left( \frac{VMA - VTM}{VMA} \right) = VFA$$

Where,

- $VMA$  = Voids in Mineral Aggregate  
 $VTM$  = Voids in Total Mix

$$100 \times \left( \frac{16.4 - 2.8}{16.4} \right) =$$

$$100 \times \left( \frac{13.6}{16.4} \right) =$$

$$100 \times .8293 = 82.9 = VFA$$

**4) Determine %  $G_{mm}$  at  $N_{initial}$  :**

$$100 \times \left( \frac{G_{mb}(h_d)}{G_{mm}(h_i)} \right) = \% G_{mm} \text{ at } N_{initial}$$

Where,

- $G_{mb}$  = Bulk Specific Gravity of mix
- $G_{mm}$  = Maximum Theoretical Specific Gravity of mix
- $h_d$  = Height at  $N_{design}$
- $h_i$  = Height at  $N_{initial}$

$$100 \times \left( \frac{2.333(117.8)}{2.399(125.9)} \right) =$$

$$100 \times \left( \frac{274.83}{302.03} \right) =$$

$$100 \times .9099 = 91.0 = \% G_{mm} \text{ at } N_{initial}$$

**5) For calculating F/A** you will need to determine two items. First, is the percent passing the 200 sieve, which can be acquired from the aggregate blending data. Second, is the percent of effective binder ( $P_{be}$ ), which is the amount of binder that is not absorbed in the aggregates.

$$P_b - \left[ (P_s \times G_b) \frac{(G_{se} - G_{sb})}{(G_{se} \times G_{sb})} \right] = P_{be}$$

Where,

- $P_b$  = Percent binder
- $P_s$  = Percent stone
- $G_b$  = Specific gravity of binder
- $G_{se}$  = Effective specific gravity of combined aggregate
- $G_{sb}$  = Specific gravity of combined aggregate

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

Where,

- $P_b$  = Percent binder
- $G_{mm}$  = Maximum Theoretical Specific Gravity of mix
- $G_b$  = Specific gravity of binder

$$\frac{(100 - 6.37)}{\frac{100}{2.399} - \frac{6.37}{1.032}} = G_{se}$$

$$\frac{93.63}{41.68 - 6.17} = G_{se}$$

$$\frac{93.63}{35.51} = 2.637 = G_{se}$$

$$6.37 - \left[ (93.63 \times 1.032) \frac{(2.637 - 2.612)}{(2.637 \times 2.612)} \right] = P_{be}$$

$$6.37 - \left[ (96.63) \frac{.025}{6.888} \right] = P_{be}$$

$$6.37 - [(96.63) .0036] = P_{be}$$

$$6.37 - .35 = 6.02 = P_{be}$$

Using the information above and the percent passing the 200 sieve (aggregate blend sheet) calculate the F/A ratio:

$$\frac{P_{.075}}{P_{be}} = \text{F/A ratio}$$

Where,

$P_{.075}$  = Percent passing 200 sieve

$P_{be}$  = Percent effective binder

$$\frac{4.9}{6.02} = .814$$

$$0.8 = \text{F/A ratio}$$

Once all the volumetric data has been calculated determine which asphalt content will be needed to achieve 4.0 percent *VTM* . Besides meeting the *VTM* requirement, the mix must meet all of the other volumetric criteria. Table 4 is a summary of the volumetric data for each of the asphalt contents tested.

**TABLE 4. Summary of Volumetric Data**

Property	2ndBlend	1st Blend	3rd Blend	Criteria
% AC	5.43	5.90	6.37	
% <i>VTM</i>	5.7	4.3	2.8	4.0
% VMA	16.9	16.5	16.4	15.0
% VFA	66.3	73.9	82.9	73-79
F/A	1.0	0.9	0.8	.6-1.2
G <sub>mm</sub>	2.434	2.420	2.399	
G <sub>mb</sub>	2.295	2.317	2.333	
N <sub>ini</sub>	87.0	88.5	91.0	90.5% max
G <sub>se</sub>	2.640	2.643	2.637	
G <sub>b</sub>	1.032	1.032	1.032	
G <sub>sb</sub>	2.612	2.612	2.612	
P <sub>be</sub>	5.03	5.46	6.02	

In analyzing the data we can see that 5.9% asphalt gives 4.3% *VTM* and the other volumetrics are well within the allowable limits of the specification. The specification does however require that the mix be designed at 4.0% *VTM* .

The next step is to determine what asphalt content will give 4.0% *VTM* . To determine this we must estimate what asphalt content will give us the required *VTM* . This can be done by plotting the % AC versus *VTM* or by a mathematical calculation. For accuracy we will determine mathematically the % AC that will give us the required *VTM* .

$$P_{bt} - (.4 \times (4 - V_{aat} N_{des})) = P_{b, est}$$

Where,

- $P_{bt}$  = Trial percent asphalt binder content
- $V_{aat} N_{des}$  = Percent air voids in total mix at  $N_{des}$
- $P_{b, est}$  = Percent binder estimated to achieve 4% *VTM*

$$5.9 - (.4 \times (4 - 4.3)) = P_{b, est}$$

$$5.9 - (.4 \times (-0.3)) = P_{b, est}$$

$$5.9 - (-0.12) = 6.0 = P_{b, est}$$

Based on the calculation to determine  $P_{b, est}$  we have determined that 6.0% asphalt content should give a *VTM* of 4.0%. It is highly recommended that a verification be made to ensure that the  $P_{b, est}$  is an accurate value. To do this we must batch material to perform two Maximum Theoretical Specific Gravity tests and three pills. Once this has been done and the testing performed, check that the volumetric properties meet the design criteria. Table 5 shows the volumetric data that was achieved using 6.0% asphalt:

**Table 5. Mix volumetrics at 6% AC**

Property	$P_{b, est}$	Criteria
% AC	6.0	
% <i>VTM</i>	4.0	4.0
% VMA	16.6	15.0
% VFA	75.8	73-79
F/A	.9	.6-1.2
$G_{mm}$	2.415	
$G_{mb}$	2.318	
$N_{ini}$	88.1	90.5% max
$G_{se}$	2.640	
$G_b$	1.032	
$G_{sb}$	2.612	
$P_{be}$	5.61	

Based on the above volumetrics, 6.0% asphalt and gradation blend previously determined will give the desired volumetrics needed to meet specifications.

## CHAPTER 6

### Calculating Field Correction Factor

In designing and producing hot-mix asphalt mixtures, one important property that must be measured is the aggregate bulk specific gravity ( $G_{sb}$ ). This value is needed to determine the voids in the mineral aggregate (VMA) of a mixture. The Virginia Department of Transportation (VDOT) developed a method in which the aggregate effective specific gravity ( $G_{se}$ ) is determined during the mix design process and the difference between  $G_{se}$  and  $G_{sb}$  is calculated. This difference, or *offset value*, is then used during production to estimate the aggregate bulk specific gravity. The offset value is dependent on an accurate determination of binder content in the hot-mix asphalt mixture; it assumes that the aggregate properties remain fairly constant during the production process.

Calculating the Field Correction Factor is as follows:

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

Where,

- $P_b$  = Percent binder
- $G_{mm}$  = Theoretical Maximum Specific Gravity of mix
- $G_b$  = Specific Gravity of binder

$$\text{Field Correction Factor} = G_{se} - G_{sb}$$

Where,

- $G_{se}$  = Effective bulk specific gravity of the blended aggregate
- $G_{sb}$  = Bulk specific gravity of the blended aggregate

#### Example:

Using the information in Table 1 calculate the Field Correction Factor for this mix.

Table 1

$P_b$	=	6.0
$G_{mm}$	=	2.415
$G_b$	=	1.030
$G_{sb}$	=	2.612

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

Where,

- $G_{se}$  = Effective Bulk Specific Gravity of the Aggregate  
 $P_b$  = Percent binder  
 $G_{mm}$  = Theoretical Maximum Specific Gravity  
 $G_b$  = Specific Gravity of binder

$$G_{se} = \frac{(100 - 6.0)}{\frac{100}{2.415} - \frac{6.0}{1.030}}$$

$$G_{se} = \frac{94.0}{41.41 - 5.83}$$

$$G_{se} = \frac{94.0}{35.58}$$

$$G_{se} = 2.642$$

$$\text{Field Correction Factor} = G_{se} - G_{sb}$$

$$\text{Field Correction Factor} = 2.642 - 2.612 = 0.030$$

Following is an example of how the field correction factor is used during production:

Example: The QC Technician has performed volumetric testing on this surface mix. The percent asphalt content was determined to be 6.2%, the Bulk Specific Gravity of the mix was 2.326, the Field Correction Factor was 0.030, and the Theoretical Maximum Specific Gravity of the mix was 2.403. The VTM was determined to be 3.2%.

Using the information above, determine the  $G_{se}$ , estimated  $G_{sb}$  and  $VMA$ .

a) Determine  $G_{se}$ :

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

Where,

- $P_b$  = Percent binder  
 $G_{mm}$  = Theoretical Maximum Specific Gravity of the mix  
 $G_b$  = Specific Gravity of binder = 1.030

$$G_{se} = \frac{(100 - 6.2)}{\frac{100}{2.403} - \frac{6.2}{1.030}}$$

$$G_{se} = \frac{93.8}{41.61 - 6.02}$$

$$G_{se} = \frac{93.8}{35.59} = 2.636$$

b) Estimated  $G_{sb}$ :

$G_{se}$  - Field Correction Factor = estimated  $G_{sb}$

$$2.636 - 0.030 = 2.606$$

c) Determine *VMA* :

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

Where,

$G_{mb}$  = Bulk Specific Gravity of mix

$P_s$  = Percent stone (100 - % asphalt)

$G_{sb}$  = Bulk Specific Gravity of combined aggregate

$$100 \times \left( 1 - \frac{2.326(100 - 6.2)}{2.606} \right)$$

$$100 \times \left( 1 - \frac{2.326(93.8)}{2.606} \right)$$

(\* % Aggregate must be converted to a decimal by  $\frac{93.8}{100}$  .)

$$100 \times \left( 1 - \frac{2.326(0.938)}{2.606} \right)$$

$$100 \times \left( 1 - \frac{2.182}{2.606} \right)$$

$$100 \times (1 - .837)$$

$$100 \times .163 = 16.3 = VMA$$

The Field Correction Factor should be submitted to the Department when submitting a mix design.

## **Chapter 7**

### **Muffle Furnace Correction Factor**

Since the 1995 construction season, the Virginia Department of Transportation (VDOT) has allowed use of the ignition method of asphalt content determination. By 1997, VDOT had extended this method to all asphalt content determinations. Determining an accurate asphalt content necessitates a correction factor be determined to account for a perceived aggregate loss and/ or chemical reactions during ignition.

During ignition, some aggregates lose moisture that cannot be dried out in a normal oven. Other aggregates, like dolomites or limestone, undergo chemical reactions such as the expulsion of carbon dioxide, leaving behind calcite (calcite is dolomite or limestone with the CO<sub>2</sub> removed). Virginia Test Method-102 (VTM-102), 'Determination of Asphalt Content from Asphalt Paving Mixtures by the Ignition Method', uses specimens of known asphalt content to determine the muffle furnace correction factor.

With the aggregate blend and asphalt content selected for the Job Mix, the Muffle Furnace Correction Factor for the mix can now be found. The first step in determining the Muffle Furnace Correction Factor is batching the materials. Using the same methods as in the aggregate blending and asphalt blending sections, perform the batching process. Refer to VTM-102 section 5 Table 1, to determine the size of sample needed to perform this test.

#### Example:

The mix being designed is an SM-9.5A; the Nominal Maximum aggregate size for this mix is 3/8 in. (9.5mm). Referring to Table 1 in VTM-102 the minimum sample size is 1200 grams. The note under Table 1 in VTM-102 states that sample sizes should not be more than 800 grams greater than the minimum recommended sample size. Now that the sample size is known, we can determine the weights needed for each aggregate used in the blend.

For this particular mix the batch weight has been determined to be 1400 grams.

Using the information in Table 1, determine the batch weights needed for determining the Muffle Furnace Correction Factor.

**Table 1. Mixture blend percentages for example**

	<b>% blend</b>
<b>Asphalt content</b>	6
<b>Aggregates</b>	
#8	46
Sand	16
#10	38
Bag house fines	1

1) Determine the mass of asphalt needed (in grams):

$$\frac{(A \times B)}{100} = \text{Asphalt needed in grams } (C)$$

Where,

$A$  = Sample weight

$B$  = % Asphalt

$$\frac{(1400 \times 6.0)}{100} = C$$

$$\frac{8400}{100} = 84.0 \text{ Asphalt needed in grams } (C)$$

2) Determine the mass of aggregates needed:

$$A - C = \text{Aggregates needed in grams } (D)$$

Where,

$A$  = Sample weight

$C$  = Asphalt needed in grams

$$1400 - 84.0 = 1316.0 \text{ Aggregates needed in grams } (D)$$

3) Determine the mass for each aggregate used in blend:

a) #8 stone = 46% of blend:

$$\frac{(D \times E)}{100} = \text{\#8 stone needed in grams}$$

Where,

$D$  = Aggregates needed in grams  
 $E$  = % of aggregate type used for blend

$$\frac{(1316 \times 46)}{100} =$$

$$\frac{60536}{100} = 605.4 \text{ \#8 stone needed in grams}$$

b) Sand = 16% of blend:

$$\frac{(D \times E)}{100} = \text{Sand needed in grams}$$

Where,

$D$  = Aggregates needed in grams  
 $E$  = % of aggregate type used for blend

$$\frac{(1316 \times 16)}{100} =$$

$$\frac{21056}{100} = 210.6 \text{ Sand needed in grams}$$

c) #10 Stone = 37% of blend:

$$\frac{(D \times E)}{100} = \text{\#10 stone needed in grams}$$

Where,

$D$  = Aggregates needed in grams  
 $E$  = % of aggregate type used for blend

$$\frac{(1316 \times 37)}{100} =$$

$$\frac{48692}{100} = 486.9 \text{ \#10 stone needed in grams}$$

d) Bag house fines = 1% of blend

$$\frac{(D \times E)}{100} = \text{Bag house fines needed in grams}$$

Where,

$D$  = Aggregates needed in grams

$E$  = % of aggregate type used for blend

$$\frac{(1316 \times 1)}{100} =$$

$$\frac{1316}{100} = 13.2 \text{ Bag house fines needed in grams}$$

To ensure that no math errors have occurred, it is *highly* recommended that after calculating the weights needed, the mix design technician should sum the weights needed for each component and compare the total to the original sample weight specified.

Example: Checking Calculated Component Weights to Sample Weight

Pill Weights:

Aggregates	Weights in grams
#8	605.4
Asphalt sand	210.6
#10	486.9
Bag house fines	13.2
Liquid Asphalt	84
<b>Total</b>	<b>*1400.1</b>

*\* The sum of weights needed in grams should be very close to the pill weight that was originally specified.*

VTM-102 requires that five samples be batched- one sample for buttering the mixing equipment and four samples for determining the Muffle Furnace Correction Factor. For accuracy it is recommended that each specimen be batched separately. In bulk batching the material, full coating of the aggregate may not occur, which affects the asphalt content and resulting Muffle Furnace Correction Factor.

Once the weights have been determined for each aggregate, the material is batched for testing. It is recommended that for batching materials that you weigh the finer material first then proceed to the coarser material. The specification requires a forced air oven be used for

heating the material for mixing and compaction; if the finer material is on top, it will tend to get blown out of the pan. As always, when batching aggregates, a flat bottom scoop is required.

Now that the material has been batched and the binder selected it is now time to heat the aggregates, binder and mixing equipment to the proper mixing temperature. Section 211.03(d)6 of the *Road and Bridge Specifications* lists the proper mixing and compaction temperatures for each grade type of binder. The mix that is being designed is a SM-9.5A thus the mixing temperature is 300° F to 310° F. Set the oven to the proper mixing temperature and place the aggregates, binder and mixing equipment in the oven. A dial thermometer with a range of 50° F to 400° F should be placed in each pan of material and in the binder to ensure the materials have achieved the proper mixing temperature.

Once the material has reached the specified mixing temperature proceed with combining the liquid asphalt and aggregates. Always thoroughly mix each sample after adding the liquid asphalt (*remember that the first sample to be mixed is the butter batch*). For determining the Muffle Furnace Correction Factor, aging the mix for two hours is not required. Once the material has been mixed, VTM-102 is followed. Section 6 of VTM-102 gives the procedure to follow for determining the calibration factor. Part of section 6 of VTM-102 follows:

## 6. Calibration

*A mixture calibration procedure is required.* For mix designs containing RAP, sufficient quantity of RAP should be sampled such that the binder content of the RAP may be estimated, and to provide for the RAP to be used in the mix calibration. The binder content of the RAP will be estimated from the average of four samples (RAP only) burned in the furnace. The portions of RAP should be obtained using a sample splitter.

Typically, calibration testing will be performed at 538 °C (1000 °F). However, certain aggregate types may result in an unusually high calibration factor and erroneous gradation results. Such mixes should be calibrated and tested at a lower temperature, typically 482 °C (900 °F) as approved by the Engineer.

**6A. Calibration Procedure for Hot-Mix Asphalt**

6A.1 This method may be affected by the type of aggregate in the mixture. Accordingly, to optimize accuracy, a calibration factor will be established with the testing of a set of calibration samples for each mix type. This procedure must be performed before any acceptance testing is completed.

6A.2 *Four calibration specimens conforming to the mass requirements of Section 5.2.2 shall be prepared at the optimum asphalt content. A butter mix shall be prepared at the design asphalt content, mixed and discarded prior to mixing any of the calibration specimens to ensure an accurate asphalt content. Aggregate used for the calibration specimens shall be sampled from stockpiled material produced in the current construction season. Any method may be used to combine the aggregates, however an additional “blank” specimen shall be batched and tested according to AASHTO T 30. The washed gradation shall fall within the JMF (mix design) tolerances.*

***NOTE:** When batching calibration samples, be sure to account for the AC% contribution of the RAP to the total asphalt content of the specimens.*

6A.3 The freshly mixed specimens may be placed directly in the sample basket(s). If allowed to cool, the samples must be preheated in a 125°C (257°F) oven for 25 minutes. Do not preheat the sample basket(s).

6A.4 Preheat the ignition furnace to 538°C (1000°F). Record the furnace temperature (set point) prior to the initiation of the test.

6A.4 Enter a calibration factor of **0.00** in the ignition furnace.

- 6A.5 Weigh and record the weight of the sample basket(s) and catch pan (with guards in place).
- 6A.6 Place the sample basket in the catch pan. Evenly distribute the calibration specimen in the basket taking care to keep the material away from the edges of the basket. Use a spatula or trowel to level the specimen.
- 6A.7 When multiple sample baskets are used, place a sample basket in the catch pan. Evenly distribute an equal portion of the specimen in the basket, taking care to keep the material away from the edges of the basket. Each subsequent basket should be placed on top of the preceding basket with an equal portion of the specimen evenly distributed in each basket. Care should be taken to keep the material away from the edges of the baskets. Use a spatula or trowel to level the specimen.
- 6A.8 Weigh and record the sample, basket(s), catch pan, and basket guards. Calculate and record the initial weight of the sample specimen (total weight - the weight of the sample basket assembly).
- 6A.9 Input the initial weight of the sample specimen in whole grams into the ignition furnace controller. Verify that the correct weight has been entered.
- 6A.10 Open the chamber door and place the sample basket(s) in the furnace. Close the chamber door and verify that the sample weight (including the basket(s) displayed on the furnace scale equals the total weight recorded in Section 6.8 within  $\pm 5g$ . Differences greater than 5 grams or failure of the furnace scale to stabilize may indicate that the sample basket(s) are contacting the furnace wall. Initiate the test by pressing the start/stop button. This will lock the sample chamber and start the combustion blower.
- 6A.11 Allow the test to continue until the stable light and audible stable indicator indicates the test is complete. Press the start/stop button. This will unlock the sample chamber and cause the printer to print out the test results.

6A.12 Open the chamber door, remove the sample basket(s) and allow to cool to room temperature (approx. 30 minutes).

6A.13 Perform a gradation analysis on the residual aggregate as indicted in Section 8.

6A.14 Once all of the calibration specimens have been burned, determine the difference between the actual and measured asphalt contents for each sample. The mix calibration factor is calculated as follows:

$$\text{MCA} = \frac{\text{AC}\% \text{ test 1} + \text{AC}\% \text{ test 2} + \text{AC}\% \text{ test 3} + \text{AC}\% \text{ test 4}}{4}$$

where:

MCA = Mixture Calibration Average

AC % = Difference between actual binder content (including RAP AC%) and measured asphalt content

After completing section 6 of VTM-102 we can now determine the correction factor for this mix.

Example:

Sample	Actual AC%	Measured Corr. AC%	Difference Measured - Actual
1	6.00	6.48	.48
2	6.00	6.42	.42
3	6.00	6.45	.45
4	6.00	6.39	.39
<b>Average</b>			<b>.44</b>

For this mix, the Muffle Furnace Correction Factor will be reported as 0.44. When submitting the Job Mix for review the Mix Design technician will need to submit the tickets for each burn, the Statement of Ashing Furnace Calibration for Asphalt Concrete and the gradation associated with each burn.

## CHAPTER 8

### Testing %G<sub>mm</sub> at N<sub>max</sub>

Once the aggregate blend and percent asphalt have been determined for design submittal it is now time to perform  $N_{max}$ . This consists of batching a minimum of two pills at the design asphalt content. The Maximum Theoretical Specific Gravity ( $G_{mm}$ ) was determined at the design asphalt content when performing the asphalt blending so there is no need to rerun this test. Section 211, Table II-14 of the *Road and Bridge Specifications* lists the gyration level required to achieve  $N_{max}$ . In AASHTO M323 the criteria for  $N_{max}$  is listed in Table 6, which is less than or equal to 98 percent of Maximum Theoretical Specific Gravity. The first step in this process is to batch the aggregates for mixing. This is done by following the same steps as in the asphalt blending chapter.

#### $N_{max}$ (Pills) at 6.0% Asphalt

Using the information from Table 1 determine the batch weights for the pills:

**Table 1. Sample data**

Pill weight:	4600g	
Aggregates	% blend	Asphalt content
#8	46	6.0%
sand	16	
#10	38	
bag house fines	1	

1) Determine the mass of asphalt needed in grams:

$$\frac{(A \times B)}{100} = \text{Asphalt needed in grams } (C)$$

Where,

$A$  = Pill weight

$B$  = % Asphalt

$$\frac{(4600 \times 6.0)}{100} = C$$

$$\frac{27600}{100} = C$$

$$276.0 = \text{Asphalt needed in grams } (C)$$

- 2) Determine the mass of aggregates needed:

$$A - C = \text{Aggregates needed in grams } (D)$$

Where,

$A$  = Pill weight

$C$  = Asphalt needed in grams

$$4600 - 276.0 = 4324.0 \text{ Aggregates needed in grams } (D)$$

- 3) Determine the mass for each aggregate used in blend:

- a) #8 stone - 46% of blend:

$$\frac{(D \times E)}{100} = \text{\#8 stone needed in grams}$$

Where,

$D$  = Aggregates needed in grams

$E$  = % of aggregate type used for blend

$$\frac{(4324 \times 46)}{100} =$$

$$\frac{198904}{100} =$$

$$1989.0 = \text{\#8 stone needed in grams}$$

- b) Sand – 16% of blend:

$$\frac{(D \times E)}{100} = \text{Sand needed in grams}$$

Where,

$D$  = Aggregates needed in grams

$E$  = % of aggregate type used for blend

$$\frac{(4324 \times 16)}{100} =$$

$$\frac{69184}{100} =$$

$$691.8 = \text{Sand needed in grams}$$

- c) #10 Stone – 37% of blend:

$$\frac{(D \times E)}{100} = \text{\#10 stone needed in grams}$$

Where,

*D* = Aggregates needed in grams

*E* = % of aggregate type used for blend

$$\frac{(4324 \times 37)}{100} =$$

$$\frac{159988}{100} = 1599.9 \text{ \#10 stone needed in grams}$$

d) Bag house fines – 1% of blend

$$\frac{(D \times E)}{100} = \text{Bag house fines needed in grams}$$

Where,

*D* = Aggregates needed in grams

*E* = % of aggregate type used for blend

$$\frac{(4324 \times 1)}{100} =$$

$$\frac{4324}{100} = 43.2 \text{ Bag house fines needed in grams}$$

*Note: Butter batch and 2 pills are required for  $N_{max}$ .*

To ensure that no math errors have occurred, it is *highly* recommended that after calculating the weights needed for the pills, the mix design technician should sum the weights needed of each component and compare the total to the original pill weight specified.

Example: Checking Calculated Component Weights to Pill Weight

**Pill Weights:**

Aggregates	Weights in grams
#8	1989.0
Asphalt sand	691.8
#10	1599.9
Bag house fines	43.2
Liquid Asphalt	276
<b>Total</b>	<b>*4599.9</b>

*\* The sum of weights needed (in grams) should be very close to the pill weight originally specified.*

Once the masses have been determined for each aggregate, the materials can be batched for

testing. It is recommended that in batching materials the mix design technician weigh the finer material first then proceed with the coarser material. The reason for this approach is that specifications require a forced air oven for heating the material for mixing and compaction. If the finer material is on top, it will tend to get blown out of the pan. As always, when batching aggregates, a flat bottom scoop is required.

The mix being designed is a SM-9.5A so the PG binder type to be used is PG64-22. Refer to section 211.01 of the *Road and Bridge Specifications* to find the binder grade to use for a specified mix type.

After the material is batched and the binder selected, the aggregates, binder and mixing equipment are heated to the proper mixing temperature. Section 211.03(d)6 of the *Road and Bridge Specifications* lists the proper mixing and compaction temperatures for each grade type of binder.

The mix that is being designed is a SM-9.5A and the mixing temperature is 300° F to 310° F. Set the oven to the proper mixing temperature and place the aggregates, binder and mixing equipment into the oven. A dial thermometer with a range of 50° F to 400° F should be placed in each pan of material and in the binder to ensure that the materials have reached the proper mixing temperature. Once the materials have reached the specified mixing temperature proceed with combining the aggregates and liquid asphalt (always remember that the first sample to be mixed is the butter batch).

Charge the mixing bowl with the heated aggregate and mix thoroughly. Form a crater in the dry blended aggregate, and weigh the required amount of binder into the mix. Immediately start mixing. AASHTO PP-28 does allow the material to be mixed using a mechanical mixer or by hand mixing. Whichever method of mixing is used, mixing must be uniform and with minimal loss of temperature.

After mixing, the material must be aged. AASHTO PP2-01 section 7.1.2 states that the material must be aged at the specified compaction temperature for 2 hours  $\pm$  5 minutes. The compaction temperature for this mix is 285° F. to 290° F. (Refer to section 211.03(d) 6 of the *Road and Bridge Specifications* to find the proper compaction temperature.)

After the material has aged, the specimen is compacted in the Gyratory compactor (AASHTO T312-01) using  $N_{max}$  gyrations as given in Table II-14 of the *Specifications*. Allow the compacted specimens to cool to room temperature (16 Hours) before determining Bulk Specific Gravity of the compacted specimen (AASHTO T166-00).

**Bulk Specific Gravity ( $G_{mb}$ ) =**

$$\frac{A}{(B - C)} = G_{mb}$$

Where,

- $A$  = Weight in air
- $B$  = Weight saturated surface dry
- $C$  = Weight in water

Sample Calculation of  $G_{mb}$ :

	Sample 1	Sample 2
Weight in Air (A)	4598.6	4596.3
SSD Weight (B)	4600.6	4598.5
Weight in Water (C)	2641.2	2641.0

**1<sup>st</sup> Sample:**

$$\frac{A}{(B - C)} = G_{mb}$$

$$\frac{4598.6}{(4600.6 - 2641.2)} = \frac{4598.6}{1959.4} =$$

$$2.347 = G_{mb}$$

**2<sup>nd</sup> Sample:**

$$\frac{A}{(B - C)} = G_{mb}$$

$$\frac{4596.3}{(4598.5 - 2641.0)} = \frac{4596.3}{1957.5} =$$

$$2.348 = G_{mb}$$

Average  $G_{mb}$  of two samples = **2.348**

Using the Maximum Theoretical Specific Gravity ( $G_{mm}$ ) value obtained when verifying the target percent asphalt content, we can determine the percent density of the mix at  $N_{max}$ . The following shows how to perform this calculation:

$$100 \times \left( \frac{G_{mb}}{G_{mm}} \right) = \%G_{mm_{max}}$$

Where,

$$\begin{aligned} \%G_{mm_{max}} &= \% \text{ density at } N_{max} \text{ gyrations} \\ G_{mb} &= \text{Bulk Specific Gravity of mix} \\ G_{mm} &= \text{Maximum Theoretical Specific Gravity} \end{aligned}$$

$$100 \times \left( \frac{2.348}{2.415} \right)$$

$$100 \times (.972) = 97.2 \%G_{mm_{max}}$$

Once the  $\%G_{mm_{max}}$  has been determined refer to AASHTO M323 (Table 6) to see if the mix meets the established criteria. This mix does meet the established criteria for  $N_{max}$  which is that the percent of Theoretical Maximum Specific Gravity reached at  $N_{max}$  be less than 98%. That is,  $\%G_{mm_{max}} \leq 98\%$  of  $G_{mm}$  for the mix.

## **CHAPTER 9**

### **Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage(TSR)**

Once the design is complete, the final step in the mix design process is determining the amount of anti-strip additive to be used to prevent stripping of the material. The designer, when determining which additive to use can choose either hydrated lime or a chemical additive. If hydrated lime is used as an anti-stripping additive it must be incorporated into the design phase for the aggregate blend and asphalt blending procedure. If a chemical additive is used it must be one from the approved list found in VDOT's Manual of Instructions.

Once the Mix Design technician has determined the type of additive he/she is going to use they must then determine the amount of additive to use that will give the mix the necessary Tensile Strength Ratio. The Tensile Strength Ratio is a way of estimating the stripping potential of the mix. The 'Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage (TSR)' AASHTO T-283 is a test used to determine if the amount of anti-stripping additive is sufficient to reduce the potential for stripping. For the TSR test the following procedures should be reviewed: Section 211.02(H) of the *Road and Bridge Specifications*, AASHTO T-283, T-166, T-209, T-269 and ASTM D 3549.

For this particular mix, the mix design technician has decided to use a chemical additive from the approved list. Once he/she has determined which additive to use the next step is to determine the amount needed to give a TSR value that meets specification. To determine the amount needed the mix design technician will need to have knowledge of the history of the materials used in their mixes. If the mix design technician does not have this information he/she can contact the manufacturer and they should be able to give a good starting point. For this example the design technician has decided to use 1.0% of product X in the blend.

The Department allows two methods for compaction of specimens, the Field Marshall compactor and the Gyrotory compactor. The technician will need to batch a butter sample, eight pills and one rice to perform this test. For batching the material, the technician will need to follow the same procedure that was done in the Aggregate Blend and Asphalt Blend chapters.

The chemical additive will need to be added to the liquid asphalt prior to adding the asphalt to the aggregates. For example, this mix is going to have 1% chemical additive so the technician is going to need roughly 1000 grams of asphalt to batch a butter batch, eight pills and a rice.

Now that he/she knows the amount of asphalt to perform the test, the next step is to calculate the amount of additive for the asphalt. The following is the calculation for determining the amount of additive to add to achieve 1% of the blend:

$$\frac{\text{Weight of asphalt} \times \text{Percent chemical additive}}{100}$$

$$\frac{1000 \times 1}{100}$$

$$10 = \text{chemical additive needed in grams}$$

Note: Some asphalt suppliers will add the chemical additive at the terminal. If the asphalt supplier is supplying the binder that has the chemical additive already in the binder then this step is not needed.

Once the material has been mixed the specimens to be compacted will need to be set out at room temperature for  $2.0 \pm 0.5$  hours. Then the material will be put in an oven at  $275^{\circ}$  F for 2 hours prior to compaction. The sample mixed for performing the Rice Test will be put into an oven at the specified compaction temperature for 2 hours  $\pm$  5 minutes. Once the material has aged proceed with the Rice test. (Note: Proper compaction temperatures can be found in section 211.03(d)6 of the *Road and Bridge Specifications*.)

Now that the specimens for the TSR test have been through the aging process the next step is compaction of specimens. For specimens compacted with the Marshall hammer the specimens will be compacted to a height of 2.5 inches. If the Gyratory compactor is used, the specimens will be compacted to 3.5 inches in height. The goal, no matter what compactor is used, is to achieve  $7 \pm 1$  percent air voids.

Once the specimens have been compacted, extracted from the molds and allowed to cool, the technician will measure the specimens' thickness by following ASTM D 3549. The technician will need to record the specimens' thickness; these values will be used in later calculations.

The next step is to calculate the air voids:

Sample I.D.		1	2	3	4	5	6	7	8
Diameter, in.	D	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Thickness, in.	t	2.50	2.49	2.51	2.50	2.51	2.51	2.52	2.51
Dry weight in air, gm.	A	1135.6	1135.0	1134.8	1135.7	1135.2	1134.3	1134.8	1135.6
Weight in water, gm.	C	629.9	628.6	631.2	631.1	633	632.8	632.2	630.2
S.S.D. weight, gm.	B	1139.2	1139.4	1138.2	1139.8	1139.2	1137.8	1138.2	1140.5
Volume, B-C, cc	E	509.3	510.8	507.0	508.7	506.2	505.0	506.0	510.3
$G_{mb}$ , A/E	F	2.230	2.222	2.238	2.233	2.243	2.246	2.243	2.225
$G_{mm}$	G	2.415	2.415	2.415	2.415	2.415	2.415	2.415	2.415
% Air Void, $100(G-F)/G$	H	7.67	8.00	7.32	7.55	7.14	6.99	7.14	7.90
Volume Air Void, HE/100	I								
Load, pounds	P								
Dry - PC									

Once the technician has determined the percent air voids in the specimens he/she will determine if the material meets AASHTO T-283. If the cores do not meet the criteria, the cores will be discarded and the process repeated. To adjust the void content the technician will need to adjust the batch weights. For example if the cores were low in air voids the core weights will need to be decreased, and if the void content was high then the core weights will need to be increased. For this example the cores did meet the criteria in AASHTO T-283, so the next step is to determine which specimens will be used for the dry specimens and which cores will be used for the preconditioned specimens.

The specification requires 3 cores be used for the preconditioned specimens and 3 for the dry cores. To do this the technician will discard the 2 cores that are not representative of the percent air voids of all the cores. For this example cores numbered 2 and 8 will not be used for determining the TSR value as seen in Table 1.

**Table 1. Selecting two specimens from the set of eight to exclude from further testing**

Sample I.D.		1	2	3	4	5	6	7	8
Diameter, in.	D	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Thickness, in.	t	2.50	2.49	2.51	2.50	2.51	2.51	2.52	2.51
Dry weight in air, gm.	A	1135.6	1135.0	1134.8	1135.7	1135.2	1134.3	1134.8	1135.6
Weight in water, gm.	C	629.9	628.6	631.2	631.1	633	632.8	632.2	630.2
S.S.D. weight, gm.	B	1139.2	1139.4	1138.2	1139.8	1139.2	1137.8	1138.2	1140.5
Volume, B-C, cc	E	509.3	510.8	507.0	508.7	506.2	505.0	506.0	510.3
G <sub>mb</sub> , A/E	F	2.230	2.222	2.238	2.233	2.243	2.246	2.243	2.225
G <sub>mm</sub>	G	2.415	2.415	2.415	2.415	2.415	2.415	2.415	2.415
% Air Void, 100(G-F)/G	H	7.67	8.00	7.32	7.55	7.14	6.99	7.14	7.90
Volume Air Void, HE/100	I								
Load, pounds	P								
Dry - PC									

To determine which 3 cores will be used for the preconditioned specimens and which 3 cores will be used for the dry cores the technician will average the 6 cores to determine the average percent void content then he/she will split the 6 cores in half so that the average of the preconditioned specimens and dry cores are as close as possible to the average of the 6. The results of this selection are seen in Table 2.

**Table 2. Selection of cores for dry vs. preconditioned testing.**

Sample I.D.		1	2	3	4	5	6	7	8
Diameter, in.	D	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Thickness, in.	t	2.50	2.49	2.51	2.50	2.51	2.51	2.52	2.51
Dry weight in air, gm.	A	1135.6	1135.0	1134.8	1135.7	1135.2	1134.3	1134.8	1135.6
Weight in water, gm.	C	629.9	628.6	631.2	631.1	633	632.8	632.2	630.2
S.S.D. weight, gm.	B	1139.2	1139.4	1138.2	1139.8	1139.2	1137.8	1138.2	1140.5
Volume, B-C, cc	E	509.3	510.8	507.0	508.7	506.2	505.0	506.0	510.3
G <sub>mb</sub> , A/E	F	2.230	2.222	2.238	2.233	2.243	2.246	2.243	2.225
G <sub>mm</sub>	G	2.415	2.415	2.415	2.415	2.415	2.415	2.415	2.415
% Air Void, 100(G-F)/G	H	7.67	8.00	7.32	7.55	7.14	6.99	7.14	7.90
Volume Air Void, HE/100	I								
Load, pounds	P								
Dry - PC		Dry	XXX	PC	PC	Dry	Dry	PC	XXX

Avg.% air Voids PC: 7.34  
 Avg. % Air Voids Dry: 7.27

Now that the technician has determined which specimens are dry, he/she can set them aside until the preconditioned specimens have gone through the freeze thaw cycles. The 3 preconditioned specimens must now be put into a vacuum container filled with distilled water at least one inch above the specimens. Apply a vacuum of 13 – 67 kPa absolute pressure (10 – 26 in. Hg partial pressure) for a short time (5 – 10 minutes). Remove the vacuum and leave the specimen submerged in water for a short time (5 – 10 minutes).

Once this is done the technician will get the weight in water and SSD weight of the specimens then determine the degree of saturation of the specimens.

The degree of saturation shall be between 55 to 80 percent. If the samples are under 55 percent the specimens will be put back in the vacuum and the process repeated. If the specimens are above 80 percent then the samples are over saturated and the specimens shall be discarded. The technician will have to re-batch the material and start from scratch. Therefore, it is very critical that the technician not over saturate the specimens.

Sample I.D.		1	3	4	5	6	7
Diameter, in.	D	4.00	4.00	4.00	4.00	4.00	4.00
Thickness, in.	t	2.50	2.51	2.50	2.51	2.51	2.52
Dry weight in air, gm.	A	1135.6	1134.8	1135.7	1135.2	1134.3	1134.8
Weight in water, gm.	C	629.9	631.2	631.1	633	632.8	632.2
S.S.D. weight, gm.	B	1139.2	1138.2	1139.8	1139.2	1137.8	1138.2
Volume, B-C, cc	E	509.3	507.0	508.7	506.2	505.0	506.0
G <sub>mb</sub> , A/E	F	2.230	2.238	2.233	2.243	2.246	2.243
G <sub>mm</sub>	G	2.415	2.415	2.415	2.415	2.415	2.415
% Air Void, 100(G-F)/G	H	7.67	7.32	7.55	7.14	6.99	7.14
Volume Air Void, HE/100	I		37.10	38.43			36.10
Load, pounds	P						
Dry - PC		Dry	PC	PC	Dry	Dry	PC

Avg. PC: 7.34  
 Avg. Dry: 7.27

Weight in water, gm.	C'	----	660.8	661.2	----	----	658.2
S.S.D. weight, gm.	B'	----	1167.0	1169.0	----	----	1165.0
Volume, B' – C', cc	E'	----	506.2	507.8	----	----	506.8
Vol. Abs. Water B' – B, cc	J'	----	28.8	29.2	----	----	26.8
% Saturation, 100J'/I		----	77.6	76.0	----	----	74.2

Now that the technician has determined that the degree of saturation meets the requirements of AASHTO T-283 he/she can now proceed with conditioning of the specimens. The first step in this process is to wrap the specimens in cellophane, then place the specimens in a zip lock bag. Before closing the bag 10 ml of distilled water is added. Once this is done the specimens are placed in a freezer at a temperature of  $0^{\circ} \pm 5^{\circ}$  F. for a minimum of 16 hours.

After removal from the freezer, place the specimens in a bath containing distilled water at  $140^{\circ} \pm 2^{\circ}$  F. for  $24 \pm 1$  hours. As soon as possible after placement in the bath, remove the cellophane from each specimen. After  $24 \pm 1$  hours in the  $140^{\circ}$  F. water bath, remove the specimens and place them and the dry specimens in a water bath already at  $77^{\circ} \pm 1^{\circ}$  F. for  $2 \pm$  hours.

*Note: The dry specimens must be wrapped in cellophane to prevent moisture from entering the specimens.*

The next step is to determine the indirect tensile strength of the dry and conditioned specimens. Remove the specimen from the  $77^{\circ}$  F. water bath and place between the two bearing plates in the testing machine. Care must be taken so that the load is applied along the diameter of the specimen. If steel loading strips are used, record the maximum compressive strength noted on the testing machine, and continue loading until a vertical crack appears.

Remove the specimen from the machine and pull it apart at the crack. Inspect the interior surface for stripping and record observations. If steel loading strips are not used, stop loading as soon as the maximum compressive load is reached. Record the maximum compressive load. Remove the specimen, measure, and record the side (edge) flattening to the nearest .1mm (.1 in.). The flattening may be easier to measure if the flattened edge is rubbed with the lengthwise edge of a piece of chalk. After recording the flattening, replace the specimen in the compression machine and compress until a vertical crack appears. Remove the specimen from the machine and pull apart at the crack. Inspect the interior surface for stripping and record observations.

Perform calculations to determine TSR value.

Sample I.D.		1	3	4	5	6	7
Diameter, in.	D	4.00	4.00	4.00	4.00	4.00	4.00
Thickness, in.	t	2.50	2.51	2.50	2.51	2.51	2.52
Dry weight in air, gm.	A	1135.6	1134.8	1135.7	1135.2	1134.3	1134.8
Weight in water, gm.	C	629.9	631.2	631.1	633	632.8	632.2
S.S.D. weight, gm.	B	1139.2	1138.2	1139.8	1139.2	1137.8	1138.2
Volume, B-C, cc	E	509.3	507.0	508.7	506.2	505.0	506.0
G <sub>mb</sub> , A/E	F	2.230	2.238	2.233	2.243	2.246	2.243
G <sub>mm</sub>	G	2.415	2.415	2.415	2.415	2.415	2.415
% Air Void, 100(G-F)/G	H	7.67	7.32	7.55	7.14	6.99	7.14
Volume Air Void, HE/100	I		37.10	38.43			36.10
Load, pounds	P	2575			2750	2700	
Dry - PC		Dry	PC	PC	Dry	Dry	PC

Avg. PC: 7.34

Avg. Dry: 7.27

Weight in water, gm.	C'	----	660.8	661.2	----	----	658.2
S.S.D. weight, gm.	B'	----	1167.0	1169.0	----	----	1165.0
Volume, B' - C', cc	E'	----	506.2	507.8	----	----	506.8
Vol. Abs. Water B' - B, cc	J'	----	28.8	29.2	----	----	26.8
% Saturation, 100J'/I		----	77.6	76.0	----	----	74.2

Load, pounds	P''	----	2475.0	2500.0	----	----	2550.0
Dry Strength, 2P'/tDπ	Std	163.9	----	----	174.4	171.2	----
Wet Strength, 2P''/tDπ	Stm	----	156.9	159.2	----	----	161.0
Visual stripping, 0 - 5		----	0	0	----	----	0

To determine the TSR value the technician will follow the following formula:

$$\text{Avg. Stm} / \text{Avg. Std} = \text{TSR value}$$

$$169.8 / 159.0 = 0.936$$

The TSR value for this mix is 0.936; the requirement for TSR value in section 211 of the *Road and Bridge Specifications* is that the TSR value shall not be less than 0.80. This mix does meet the specification. If the material had failed then the Mix Design technician would have to repeat the test and increase the amount of anti-stripping additive, change aggregate sources or choose another anti-stripping additive from the approved list.