APPENDIX I

PROCEDURES FOR THE DETERMINATION OF HMA VOLUMETRIC PROPERTIES DURING VOLUMETRIC MIX DESIGN AND PRODUCTION

HMA producers must submit a QC plan and perform required testing to satisfy Publication 408 specifications. The QC plan shall meet or exceed the following requirements for the evaluation of the Theoretical Maximum Specific Gravity (Gmm) of the mixture and the Voids in the Mineral Aggregate (VMA). Collect one daily mixture sample of sufficient size to evaluate compliance with all applicable QC criteria identified in Publication 408, Section 409.

During production, changes in aggregate properties (especially for gravel and slag aggregates) are common. Aggregate specific gravity changes can affect the Gmm of the bituminous mixture and thus the compaction results. Significant changes in the bulk specific gravity of the combined aggregate (Gsb), can affect volumetric property calculations. Therefore, it is desirable to monitor aggregate properties and use the timeliest and most accurate information available for QC calculations and testing.

1. Theoretical Maximum Specific Gravity of the Mixture (Gmm) (AASHTO T 209)

   a. **Test Method:** The theoretical maximum specific gravity (Gmm) of uncompacted (loose) Hot-Mix Asphalt (HMA) mixtures for volumetric mix design and production Quality Control (QC) is to be performed according to the most current AASHTO T 209, Test Method A-Mechanical Agitation with the following modifications (the below referenced AASHTO T 209 Sections with modifications are indexed to the AASHTO T 209-10 standard; however, these modifications will apply to all future versions of AASHTO T 209 unless otherwise modified in an official change to Bulletin 27):

      Section 6.2.3  **Vacuum Bowl** - Delete plastic bowl. Only metal vacuum bowls are to be used.

      Section 6.2.4  **Vacuum Flask for Mass Determination in Air Only** - Delete. Vacuum flasks are not permitted.

      Section 6.2.5  **Pycnometer for Mass Determination in Air Only** - Delete plastic pycnometer. Only glass or metal pycnometers are to be used.

      Section 6.4  **Vacuum Pump or Water Aspirator** - Delete Water Aspirator. Only vacuum pumps are to be used.

      Section 7.2  **Sample Size** -

      Add the following Note immediately after Table 1:

      [Note: Additional information or requirements regarding sample size would be included here.]

I - 1  Change 4
Note 4A – During pavement forensic investigations using pavement core samples, the MTD may be required to use smaller minimum sample sizes depending on the amount of material available from the pavement core sample(s).

Section 9.1 Sample Preparation - Add the following to the end of this section:

The flat pan is to be clean. A flat pan with a slight coating of asphalt binder residue from previous samples is acceptable, but the pan should not contain particles from a previous sample.

Section 9.2 Sample Preparation - Replace this subsection in its entirety with the following:

Place the mixture in a pan, and spread it to an even thickness ranging between 25 and 50 mm (1 and 2 inches). Place the mixture and pan in a forced-draft oven at an oven temperature that is the midpoint of the minimum and maximum mixture temperatures in Pub. 408, Section 409, Table A.

<table>
<thead>
<tr>
<th>PG–Binder Grade in Mixture</th>
<th>Conditioning Oven Temperature, °C (°F) (Midpoint of Minimum and Maximum Mixture Temperatures)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 58-28</td>
<td>140 ± 3 (285 ± 5)</td>
</tr>
<tr>
<td>PG 64-22</td>
<td>145 ± 3 (293 ± 5)</td>
</tr>
<tr>
<td>PG 76-22</td>
<td>153 ± 3 (308 ± 5)</td>
</tr>
<tr>
<td>Other PG Binder Grades</td>
<td>See Pub. 37, Bulletin 25 for the minimum and maximum mixture temperature ranges and use the midpoint of this range for the conditioning oven temperature ± 3°C (5°F).</td>
</tr>
</tbody>
</table>

Condition the mixture in the forced-draft oven for 2 h ± 5 minutes unless absorptive coarse aggregates are used in the JMF. Absorptive coarse aggregates are defined as any coarse aggregate source that has water absorption greater than 1.5% as determined by AASHTO T 85.

When absorptive coarse aggregates are used in the JMF, condition the mixture in the forced-draft oven for 6 h ± 5 minutes. For Gmm determinations during volumetric mix design, always condition the mixture for 6 h ± 5 minutes.
For Gmm determinations during production, if the mixture was stored in an approved surge/storage silo prior to testing, the amount of time the mixture was stored in the surge/storage silo can be subtracted from the required 2 h ± 5 minutes or the 6 h ± 5 minutes of conditioning time. However, for this time to be subtracted, the HMA Producer’s Quality Control Plan must address how the surge/storage silo time will be accurately determined each time the AASHTO T 209 test is performed. Mixtures stored in an approved surge/storage silo for more than 2 h ± 5 must be sampled and tested for Gmm and compared to the Gmm value of the mixture when tested using mixture that was not stored (i.e., stored Gmm vs. pre-stored Gmm) for significant differences as defined by Appendix I.1.b.

Stir the mixture every 60 ± 5 minutes to maintain uniform coating. After the 2 h ± 5 minutes or the 6 h ± 5 minutes, remove the mixture from the forced-draft oven. The conditioned mixture is now ready for testing.

**Note 7**—If the producer is incorporating absorptive coarse aggregates in the mixture and they can demonstrate, by a series of Gmm tests, that conditioning the mixture for less than 6 h ± 5 minutes results in a Gmm value that is the maximum when the mixture is conditioned for less than 6 h ± 5 minutes or, the increased conditioning results in an increase of Gmm of less than 0.010, the mixture conditioning period can be reduced to the minimum time required as proven by the series of tests. However, in no case shall the mixture conditioning period be less than 2 h ± 5 minutes. It is advisable to conduct the series of tests using different mixture conditioning periods during the volumetric mix design process due to the time-consuming nature of this evaluation. Do not use this reduced conditioning time for Gmm determinations during and for the volumetric mix design development. Use the reduced conditioning times for Gmm determinations only during production.


**Section 14.1.3** *Large-Size Plastic Pycnometer Determinations* - Delete. Plastic pycnometers are not permitted.
b. **Production Quality Control**: When performing production QC testing for Gmm, sample the mixture according to PTM No. 1 and PTM No. 746 at the minimum frequency specified in Publication 408, Section 409.2(e)1.d, or at any increased frequency indicated in the HMA Producer’s QC Plan.

For compaction control on the first day of production and to certify volumetric properties at the plant, use the Gmm value obtained at the plant on the first day. If this value differs significantly from the JMF value (difference of 0.030 or more), at least three tests should be run on the first day and the average used for determination of both lab and field density. If this average varies 0.020 or more from the JMF, an investigation into the cause of the variability should be conducted as outlined in 1.c.ii.

c. **Starting on the second day of production and if no problems are evident, AASHTO T 209 as modified herein, shall be run at least once daily. For small quantity production of individual mixes, test frequency may be reduced to once per 500 tons, but not less than once per week. Each value or daily average should be used for compaction control in the field for the specific day(s) represented by the test, and to certify plant volumetric properties. Plot the results on control charts.**

   i. When any test indicates a significant change in the material, testing shall be increased to three daily (using the daily average) and continued at that rate until the tests indicate a return to normal uniformity. When an individual test varies more than 0.030 from the JMF Gmm value, or the average of multiple tests conducted on the same day varies 0.020 or more from the JMF value, the change will be deemed significant.

   ii. If significant change occurs more often than occasionally the extent of the problem should be investigated more thoroughly. Changes in material properties and/or equipment and adherence to test procedures should be evaluated. In particular, production aggregates should be tested to verify that Gsb value(s) have not changed significantly (more than 0.015).

2. **Voids in the Mineral Aggregate**

   a. **Determine the VMA and other specified volumetric properties using AASHTO R 35 procedures. VMA is the volume of void space between the aggregate particles of a compacted paving mixture, composed of the air voids and the effective binder and expressed as a percent of the total volume of the specimen.**
VMA is calculated using the following formula:

\[
VMA = 100 - \frac{Gmb \times Ps}{Gsb} \quad [Eq. 1]
\]

Where:
- \( Gmb \) = bulk specific gravity of the completed mixture
- \( Ps \) = aggregate content, percent by mass (= 100 – asphalt content from QC test result).
- \( Gsb \) = bulk specific gravity of the combined aggregate

b. Changes in aggregate properties, including the bulk specific gravity of the combined aggregate (Gsb), can affect volumetric property calculations. However, determination of the Gsb using T 84 (Fine Aggregate), and T 85 (Coarse Aggregate) test methods is somewhat cumbersome. It may be impractical to conduct these tests at a frequency comparable to other QC tests. However, the effective specific gravity of the combined aggregate (Gse) can be calculated from QC information routinely gathered during mixture Gmm and asphalt content (Pb) determination:

\[
Gse = \frac{100 - Pb}{\frac{100 - Pb}{Gmm} - \frac{Pb}{Gb}} \quad [Eq. 2]
\]

Where:
- \( Pb \) = asphalt binder content, percent by mass (production QC test result)
- \( Gmm \) = theoretical maximum specific gravity of the mixture (production QC test result)
- \( Gb \) = specific gravity of the binder (current Bill of Lading result(s))

c. It is recommended that a minimum of three sets of tests should be averaged to establish the combined aggregate Gsb during the mix design process. If current Bulletin 14 values are reasonable based on historical testing records and are acceptable to both Department
and aggregate source representatives, Bulletin 14 Gsb values may be used for mix design. Calculate an offset value (Cfg) after T 209 is performed (and T 84 and T 85 if necessary):

\[ C_{fg} = (G_{se} - G_{sb}) \] \[ Eq. 3 \]

d. During production, the combined aggregate Gsb can then be estimated from:

\[ G_{sb} \approx G_{se} - C_{fg} \] \[ Eq. 4 \]

Calculate VMA using the estimated Gsb value to satisfy the production VMA requirements in Pub. 408. This method should account for variations in aggregate properties and proportions, assuming that aggregate absorption remains fairly consistent. If a change in asphalt absorption is suspected (e.g. due to a fluctuation in Gmm), Gsb should be tested, and Cfg adjusted if necessary. Also, the Gsb of each aggregate should be tested and the Cfg for the mix design revised any time the running average of three consecutive Gsb estimates (per Eq. 4) varies by more than 0.015 from the last known Gsb based on test values. Obtain aggregate Gsb test results from a source approved by the District Materials Engineer.
EXAMPLE

Given:  
  
  \( C_{fg} = 0.057 \) (determined during mix design as described above)  
  \( G_b = 1.030 \)  
  \( G_{mb} = 2.442 \) (production QC test result)  
  \( G_{mm} = 2.535 \) (production QC test result)  
  \( P_b = 5.3\% \) (production QC test result)

\[
G_{se} = \frac{\frac{100 - 5.3}{5.3}}{\frac{2.535}{1.030}} = 2.761 \quad \text{[Eq. 2]}
\]

\( G_{sb} \) can be estimated using the offset value.

\[
G_{sb} \approx 2.761 - 0.057 = 2.704 \quad \text{[Eq. 4]}
\]

Production VMA can then be calculated as shown in R 35 using the estimated \( G_{sb} \):

\[
VMA = 100 - \frac{2.442 \times (100 - 5.3)}{2.704} = 14.5\% \quad \text{[Eq. 1]}
\]

ALTERNATE PHASE DIAGRAM SOLUTION

Follow the solution clockwise around the diagram, beginning with (a) and ending at (e).

<table>
<thead>
<tr>
<th>Volume</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Assume volume of mix, ( V_m = 100 )</td>
<td>( b) \text{Mass of Mix, } M_m = )</td>
</tr>
<tr>
<td>(e) VMA=</td>
<td>( G_b \times V_m = )</td>
</tr>
<tr>
<td>( 100 - V_{sb} = )</td>
<td>( 2.442 \times 100 = )</td>
</tr>
<tr>
<td>( 100 - 85.5 = )</td>
<td>( 244.2 )</td>
</tr>
<tr>
<td>( 14.5% )</td>
<td></td>
</tr>
<tr>
<td>(d) Bulk Volume of Agg, ( V_{sb} = )</td>
<td>( c) \text{Mass of Agg, } M_s = )</td>
</tr>
<tr>
<td>( M_s )</td>
<td>( \frac{100 - P_b}{100} \times M_m = )</td>
</tr>
<tr>
<td>( \frac{G_{sb} \times 2.704}{G_{se}} = )</td>
<td>( \frac{100 - 5.3}{100} \times 244.2 = )</td>
</tr>
<tr>
<td>( 231.3 )</td>
<td>( 231.3 )</td>
</tr>
<tr>
<td>( 2.704 )</td>
<td></td>
</tr>
<tr>
<td>( 85.5 )</td>
<td></td>
</tr>
</tbody>
</table>