
Standard Method of Test for

Theoretical Maximum Specific Gravity (G_{mm}) and Density of Hot Mix Asphalt (HMA)

AASHTO Designation: T 209-12

AASHTO

1. SCOPE

1.1. This test method covers the determination of the theoretical maximum specific gravity/gravity mix maximum (G_{mm}) and density of uncompacted hot mix asphalt (HMA) at 25°C (77°F).

Note 1—The precision of the method is best when the procedure is performed on samples that contain aggregates that are completely coated. In order to assure complete coating, it is desirable to perform the method on samples that are close to the optimum asphalt binder content.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards:*

- M 231, Weighing Devices Used in the Testing of Materials
- R 47, Reducing Samples of Hot Mix Asphalt (HMA) to Testing Size
- R 61, Establishing Requirements for Equipment Calibrations, Standardizations, and Checks
- T 168, Sampling Bituminous Paving Mixtures

2.2. *ASTM Standards:*

- C670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D4311/D4311M, Standard Practice for Determining Asphalt Volume Correction to a Base Temperature

3. TERMINOLOGY

3.1. *Definitions:*

3.1.1. *density, as determined by this test method*—the mass of a cubic meter of the material at 25°C (77°F) in SI units, or the mass of a cubic foot of the material at 25°C (77°F) in inch-pound units.

3.1.2. *residual pressure, as employed by this test method*—the pressure in a vacuum vessel when vacuum is applied.

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- 3.1.3. *specific gravity, as determined by this test method*—the ratio of a given mass of material at 25°C (77°F) to the mass of an equal volume of water at the same temperature.

4. SUMMARY OF TEST METHOD

- 4.1. A weighed sample of oven-dry HMA in the loose condition is placed in a tared vacuum container. Sufficient water at a temperature of $25 \pm 0.5^\circ\text{C}$ ($77 \pm 0.9^\circ\text{F}$) is added to completely submerge the sample. Vacuum is applied for 15 ± 2 min to gradually reduce the residual pressure in the vacuum container to 3.7 ± 0.3 kPa (27.5 ± 2.5 mmHg). At the end of the vacuum period, the vacuum is gradually released. The volume of the HMA sample is obtained either by immersing the vacuum container with the sample into a water bath and determining the mass (Section 13.1) or by filling the vacuum container level full of water and determining the mass in air (Section 13.2). At the time of weighing, the temperature is measured as well as the mass. From the mass and volume measurements, the specific gravity or density at 25°C (77°F) is calculated. If the temperature employed is different than 25°C (77°F), an appropriate correction is applied.

5. SIGNIFICANCE AND USE

- 5.1. The theoretical maximum specific gravities and densities of HMA are intrinsic properties whose values are influenced by the composition of the mixtures in terms of types and amounts of aggregates and asphalt materials.
- 5.1.1. These properties are used to calculate percent air voids in compacted HMA.
- 5.1.2. These properties provide target values for the compaction of HMA.
- 5.1.3. These properties are essential when calculating the amount of asphalt binder absorbed by the internal porosity of the individual aggregate particles in HMA.

6. APPARATUS

- 6.1. Follow the procedures for performing equipment calibrations, standardizations, and checks found in R 61.
- 6.2. *Vacuum Container:*
- 6.2.1. The vacuum containers described must be capable of withstanding the full vacuum applied, and each must be equipped with the fittings and other accessories required by the test procedure being employed. The opening in the container leading to the vacuum pump shall be covered by a piece of 0.075-mm (No. 200) wire mesh to minimize the loss of fine material.
- 6.2.2. The capacity of the vacuum container should be between 2000 and 10 000 mL and depends on the minimum sample size requirements given in Section 7.2. Avoid using a small sample in a large container.
- 6.2.3. *Vacuum Bowl*—Either a metal or plastic bowl with a diameter of approximately 180 to 260 mm (7 to 10 in.) and a bowl height of at least 160 mm (6.3 in.) equipped with a transparent cover fitted with a rubber gasket and a connection for the vacuum line.
- 6.2.4. *Vacuum Flask for Mass Determination in Air Only (Section 13.2)*—A thick-walled volumetric glass flask and a rubber stopper with a connection for the vacuum line.
- 6.2.5. *Pycnometer for Mass Determination in Air Only*—A glass, metal, or plastic pycnometer.

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- 6.3. *Balance*—A balance conforming to the requirements of M 231, Class G 2. The balance shall be standardized at least every 12 months.
- 6.3.1. For the mass determination-in-water method (Section 13.1), the balance shall be equipped with a suitable apparatus and holder to permit determining the mass of the sample while suspended below the balance. The wire suspending the holder shall be the smallest practical size to minimize any possible effects of a variable immersed length.
- 6.4. *Vacuum Pump or Water Aspirator*—Capable of evacuating air from the vacuum container to a residual pressure of 4.0 kPa (30 mmHg).
- 6.4.1. When a vacuum pump is used, a suitable trap of one or more filter flasks, or equivalent, shall be installed between the vacuum vessel and vacuum source to reduce the amount of water vapor entering the vacuum pump.
- 6.5. *Vacuum Measurement Device*—Residual pressure manometer¹ or vacuum gauge to be connected directly to the vacuum vessel and capable of measuring residual pressure down to 4.0 kPa (30 mmHg) or less (preferably to zero). The gauge shall be standardized at least annually and be accurate to 0.1 kPa (1 mmHg). It shall be connected at the end of the vacuum line using an appropriate tube and either a “T” connector on the top of the vessel or a separate opening (from the vacuum line) in the top of the vessel to attach the hose. To avoid damage, the manometer shall not be situated on top of the vessel.
- Note 2**—A residual pressure of 4.0 kPa (30 mmHg) absolute pressure is approximately equivalent to a 97 kPa (730 mmHg) reading on a vacuum gauge at sea level.
- Note 3**—Residual pressure in the vacuum container, measured in millimeters of mercury, is the difference in the height of mercury in the Torricellian vacuum leg of the manometer and the height of mercury in the other leg of the manometer that is attached to the vacuum container.
- Note 4**—An example of a correct arrangement of the testing equipment is shown in Figure 1. In the figure, the purpose of the train of small filter flasks is to trap water vapor from the vacuum container that otherwise would enter the oil in the vacuum pump and decrease the pump’s ability to provide adequate vacuum. Insertion of a valve to isolate the line to each vacuum chamber can reduce wear on the bleeder valve atop each chamber and assist in tracing sealing leaks.

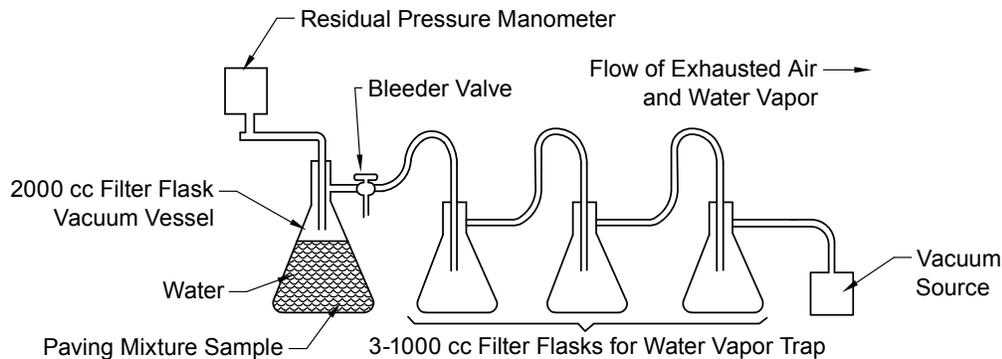


Figure 1—Example of Correct Arrangement of Testing Apparatus

- 6.6. *Bleeder Valve*—attached to the vacuum train to facilitate adjustment of the vacuum being applied to the vacuum container.
- 6.7. *Thermometric Device (Mass Determination in Air)*—A liquid-in-glass thermometer or other thermometric device, accurate to 0.5°C (1°F), of suitable range with subdivisions of 0.5°C (1°F). The thermometric device shall be standardized at the test temperature at least every 12 months.

- 6.8. *Water Bath:*
- 6.8.1. For vacuum bowls, a water bath capable of maintaining a constant temperature between 20 and 30°C (68 and 86°F) is required. (See Appendix X1 for a method for correcting the theoretical maximum specific gravity to 25°C (77°F) when measurements are made at temperatures other than 25°C (77°F)).
- 6.8.2. *Thermometric Device (Mass Determination in Water)*—A liquid-in-glass thermometer or other thermometric device, accurate to 0.5°C (1°F) shall be used to measure the temperature of the water bath. The thermometric device shall be standardized at least every 12 months.
- 6.8.3. When using the mass determination-in-water technique (Section 13.1), the water bath must be suitable for immersion of the suspended container with its deaerated sample.
- 6.9. *Drying Oven*—A thermostatically controlled drying oven capable of maintaining a temperature of 135 ± 5°C (275 ± 9°F) or 105 ± 5°C (221 ± 9°F).
- 6.9.1. *Thermometric Device*—A liquid-in-glass thermometer or other thermometric device accurate to 3°C (5°F) shall be used to measure the temperature of the oven. The thermometric device shall be standardized at least every 12 months.
- 6.10. *Protective Gloves*—Used when handling glass equipment under vacuum.

7. SAMPLING

- 7.1. Field samples shall be obtained in accordance with T 168. When necessary, reduce field samples or samples prepared or produced in a laboratory in accordance with R 47.
- 7.2. The size of the sample shall conform to the following requirements. Samples larger than the capacity of the container may be tested a portion at a time.

Table 1—Minimum Sample Sizes

| Nominal Maximum Aggregate Size, mm | Minimum Sample Size, g |
|------------------------------------|------------------------|
| 37.5 or greater | 4000 |
| 19 to 25 | 2500 |
| 12.5 or smaller | 1500 |

8. STANDARDIZATION OF FLASKS, BOWLS, AND PYCNOMETERS

- 8.1. For the mass determination-in-water method (Section 13.1), standardize the vacuum bowls for temperature correction by determining the mass of each container when immersed in water over the range of water bath temperatures likely to be encountered in service (Figure 2).

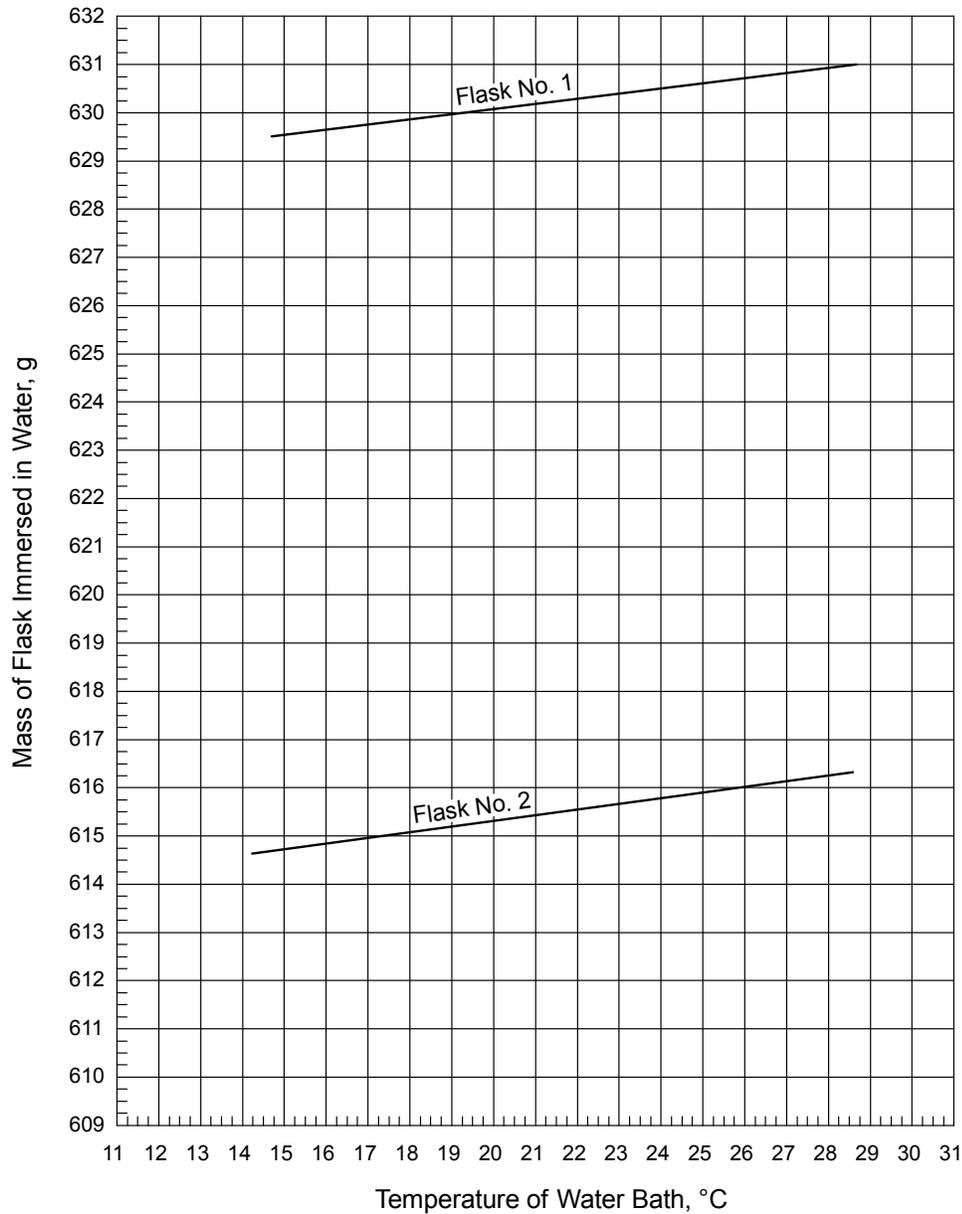


Figure 2—Example Standardization Curve for Volumetric Flask

- 8.2. For the mass determination-in-air method (Section 13.2), standardize the volumetric flasks or pycnometers for temperature correction by determining the mass of the container when filled with water over the range of water bath temperatures likely to be encountered in service (Figure 3). When standardized at $25 \pm 0.5^\circ\text{C}$ ($77 \pm 0.9^\circ\text{F}$), designate this mass as *D*. Accurate filling may be ensured by the use of a glass cover plate.

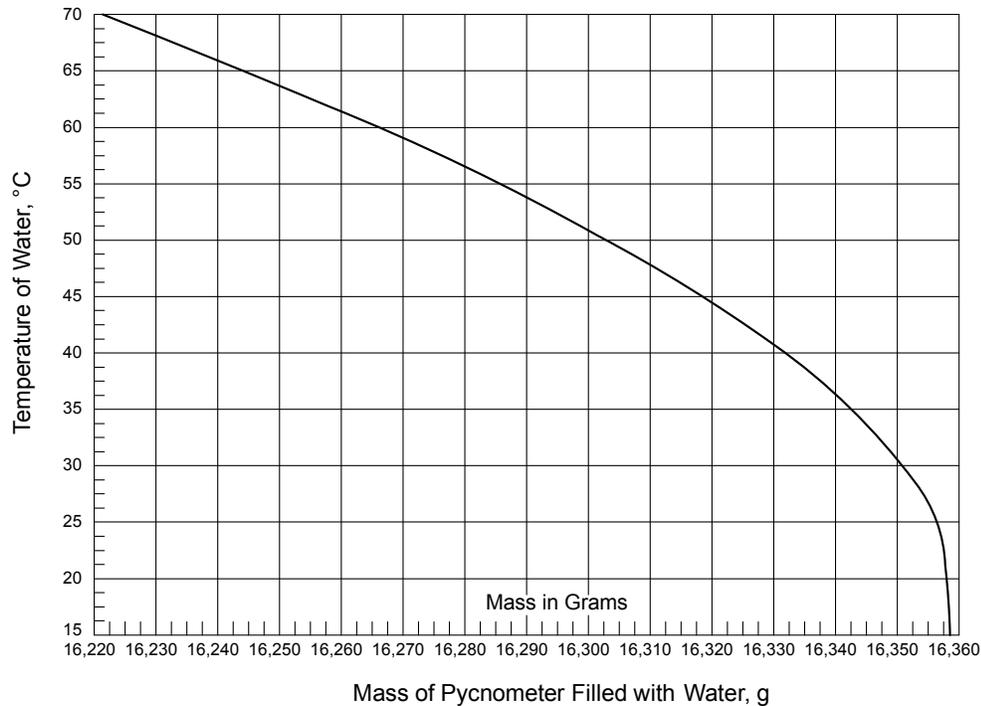


Figure 3—Example Standardization Curve for Pycnometer

- 8.3. Standardize the large-size plastic pycnometer by accurately determining the mass of water required to fill it over a range of temperature from about 20 to 65°C (70 to 150°F), and construct a standardization curve of mass versus temperature as shown in Figure 3. Care should be taken to follow exactly the same procedure in standardization as in conducting a test.
- 8.3.1. The following filling procedure may be used for the model with a latched lid and vented stopper: The domed lid is latched in place and the pycnometer nearly filled with water. Leave about 50 mm (2 in.) empty. The release of air bubbles may be facilitated by applying vacuum and by dropping first one side then the other of the pycnometer about 10 mm ($\frac{1}{2}$ in.) above a hard, flat surface. This vacuum application and bubble release procedure should take about 10 min so that the temperature equilibrium between the shell and the water approximates that attained when performing a test. The final amount of water is then gently poured in until the level is about halfway up the neck. Any air bubbles caught against the dome that cannot be released by jarring or by swirling the water may be “pricked” or pushed to the surface with a bent wire or other suitable device. Insert the vented stopper using only enough force to just seat the stopper and immediately wipe the excess water off the top.
- 8.3.2. For the models with a quick-disconnect vacuum line and unlatched lid, the filling procedure is as follows: With the inlet valve closed, apply a vacuum of about 30 kPa (225 mmHg). Open the inlet valve slowly letting water in until the level reaches 25 mm (1 in.) below the top of the dome and close the valve. Continue applying vacuum and release the bubbles by jarring and rapping the vessel with a rubber mallet. Slowly open the inlet valve and allow more water in until the water overflows into the aspirator (vacuum) line and then close the valve. This vacuum application and bubble release procedure should take about 10 min so that the temperature equilibrium between the shell and the water approximates that attained when performing a test. Disconnect the vacuum line by pulling it out at the quick-disconnect joint below the gauge.
- 8.3.3. Wipe the outside of the pycnometer dry, determine the mass of the full pycnometer, and measure the water temperature.

Note 5—The shape of the standardization curve is a function of two opposing factors that can be rationally defined. As the temperature is increased, the container itself expands (adding mass—“Pycnometer” line in Figure 4) and the density of the contained water decreases (resulting in loss of mass—“Water” line in Figure 4). These relationships are shown in Figure 4 for a typical large-size pycnometer. The “Water” curve may be constructed by multiplying the volume at 25°C (77°F) by the difference between the density of water at 25°C (77°F), which is 0.9970, and the density of water at the standardization temperature (see Equation 1).

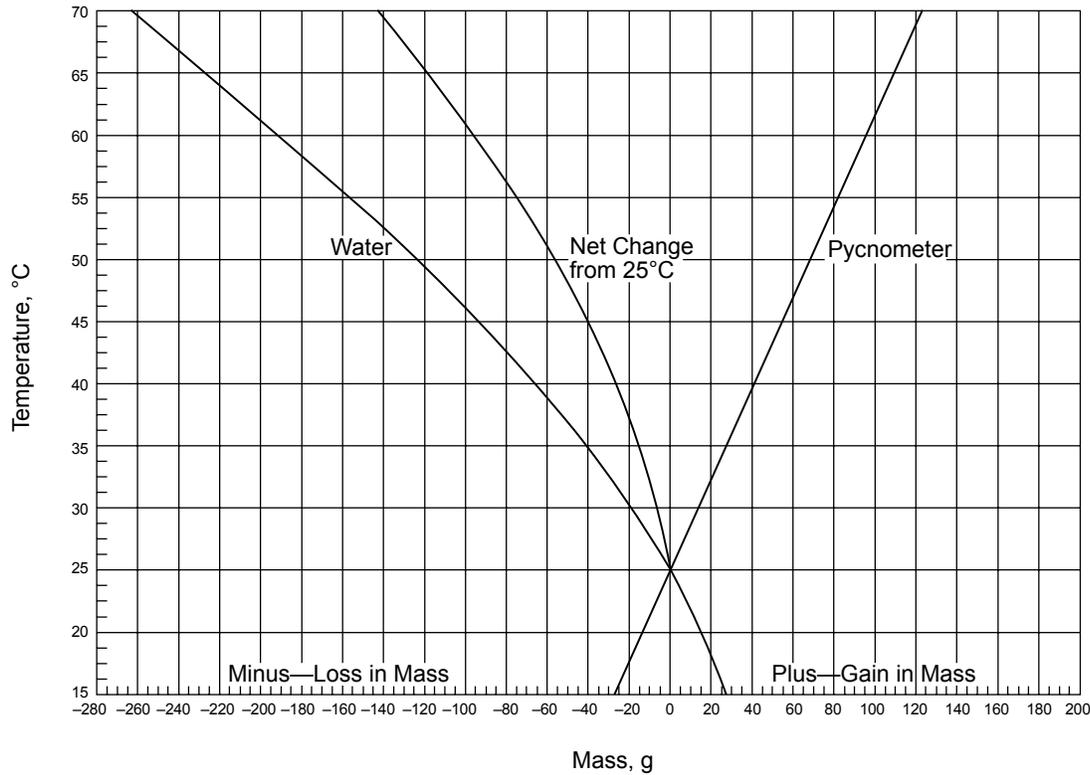


Figure 4—Effect of Change in Density of Water and Volume of Pycnometer with Change in Temperature

$$\text{difference due to water expansion} = V_{25}(0.9970 - dw)$$

$$\text{Since } V_{25} = W_{25}/0.9970$$

$$V_{25}(0.9970 - dw) \text{ reduces to } W_{25} \left(1 - \frac{dw}{0.9970} \right) \tag{1}$$

where:

V_{25} = volume of water to fill a container at 25°C (77°F), cm³;

W_{25} = mass of water to fill a container at 25°C (77°F), g; and

dw = density of water at the standardization temperature, Mg/m³.

The rate of change in capacity of the container due to thermal expansion of the pycnometer itself is essentially constant over the temperature range from 20 to 65°C (70 to 150°F). Thus, the “Pycnometer” line in Figure 4 can be drawn through the 0 at 25°C (77°F) point knowing only the slope of the straight line relationship. The slope can be established by averaging at least five standardization mass determinations at some elevated temperature, adding the loss due to water expansion and subtracting the mass at 25°C (77°F), W_{25} , to give the gain in capacity due to

expansion of the container. The difference in mass divided by the difference in temperature is the slope of the “Pycnometer” line. For a polycarbonate pycnometer of about 13 500-mL capacity, the slope thus established was 2.75 g/°C (1.53 g/°F). This value is believed to be typical and reasonably constant.

The bending of the standardization curve (Figure 3) due to these offsetting thermal factors thus minimizes experimental error due to temperature effects in the normal working range, 25°C (77°F), for both the volumetric flask and the pycnometer containers. Defining the standardization curve makes it possible to correct for temperature, rather than “bringing the container and sample to temperature,” thereby eliminating the cost of a water bath and making it feasible to improve accuracy by testing larger samples and to materially reduce the testing time.

- 8.4. While standardization of the flask or either pycnometer needs to be performed only once, the standardization should be checked occasionally, particularly at 25°C (77°F). The equipment must be kept clean and free from any accumulation that would change the mass if the volume standardization is to remain constant. Care should be taken to use only neutral solvents, especially with plastic containers; glass vessels should not be subjected to high vacuum if they are scratched or damaged.

9. SAMPLE PREPARATION

- 9.1. Separate the particles of the HMA sample by hand, taking care to avoid fracturing the aggregate, so that the particles of the fine aggregate portion are not larger than 6.3 mm (¹/₄ in.). If an HMA sample is not sufficiently soft to be separated manually, place it in a pan, and warm it in an oven until it can be separated as described.

- 9.2. Samples prepared in a laboratory shall be conditioned and dried in an oven at 135 ± 5°C (275 ± 9°F) for a minimum of 2 h or as appropriate to match the mix design procedure being used. Longer drying time may be necessary for the sample to achieve a constant mass (mass repeats within 0.1 percent). HMA that has not been prepared in a laboratory with oven-dried aggregates shall be dried to a constant mass at a temperature of 105 ± 5°C (221 ± 9°F). This drying and conditioning operation shall be combined with any warming described in Section 9.1.

Note 6—The minimum 2 h time in the oven is specified as the short-term conditioning time for laboratory-prepared specimens. The short-term conditioning at the specified temperature is especially important when absorptive aggregates are used. This short-term conditioning will ensure the computation of realistic values for the amount of asphalt absorbed by the aggregate and void properties of the mix. Plant-produced HMA should not be short-term conditioned because absorption takes place during production.

- 9.3. Cool the sample to room temperature, and place it in a tared and standardized flask, bowl, or pycnometer. The sample is to be placed directly into a vacuum container. A container within a container is not to be used. Determine the mass and designate the net mass of the sample as *A*. Add sufficient water at a temperature of approximately 25°C (77°F) to cover the sample completely.

Note 7—The release of entrapped air may be facilitated by the addition of a suitable wetting agent such as Aerosol OT in concentration of 0.001 percent or 0.2 g in 20 L of water. This solution is then diluted by about 20:1 to make a wetting agent of which 5 to 10 mL may be added to the apparatus.

TEST METHOD A—MECHANICAL AGITATION

10. APPARATUS

- 10.1. In addition to the apparatus listed in Section 6, the following apparatus is required for Method A:
- 10.1.1. *Mechanical Shaker*—Shaker for removing air from asphalt mix.

11. PROCEDURE

- 11.1. Remove air trapped in the sample by applying gradually increased vacuum until the residual pressure manometer reads 3.7 ± 0.3 kPa (27.5 ± 2.5 mmHg). Maintain this residual pressure for 15 ± 2 min. Agitate the container and contents using the mechanical device during the vacuum period. Glass vessels should be shaken on a resilient surface such as a rubber or plastic mat, and not on a hard surface, so as to avoid excessive impact while under vacuum.
- 11.2. At the end of the vacuum period, release the vacuum by increasing the pressure at a rate not to exceed 8 kPa (60 mmHg) per second and proceed with one of the mass determination methods in Section 13.

TEST METHOD B—MANUAL AGITATION

12. PROCEDURE

- 12.1. Remove air trapped in the sample by applying gradually increased vacuum until the residual pressure manometer reads 3.7 ± 0.3 kPa (27.5 ± 2.5 mmHg). Maintain this residual pressure for 15 ± 2 min. Agitate the container and contents during the vacuum period by vigorously shaking at intervals of about 2 min. Glass vessels should be shaken on a resilient surface such as a rubber or plastic mat, and not on a hard surface, so as to avoid excessive impact while under vacuum.
- 12.2. At the end of the vacuum period, release the vacuum by increasing the pressure at a rate not to exceed 8 kPa (60 mmHg) per second and proceed with one of the mass determination methods in Section 13.

13. MASS DETERMINATION

- 13.1. *Mass Determination in Water*—Suspend the container and contents in the water bath and determine the mass after a 10 ± 1 min immersion. Measure the water bath temperature, and if different from $25 \pm 1^\circ\text{C}$ ($77 \pm 2^\circ\text{F}$), correct the mass to 25°C (77°F) using the standardization temperature adjustment developed in Section 8.1. Designate the mass of the sample in water at 25°C (77°F) as *C*.
- Note 8**—Instead of using a chart like Figure 2 to establish the mass correction for the temperature of the vacuum vessel submerged by itself in the water bath, this correction can be easily established by rapidly and completely emptying the vacuum container immediately following the final mass determination, and then without delay, determining the mass of the vessel by itself when totally submerged in the water bath.
- 13.2. *Mass Determination in Air*—Fill the flask or any one of the pycnometers with water and adjust the contents to a temperature of $25 \pm 1^\circ\text{C}$ ($77 \pm 2^\circ\text{F}$). Determine the mass of the container and

contents, completely filled, in accordance with Section 8.2 within 10 ± 1 min after completing Section 11.1 or 12.1. Designate this mass as E .

Note 9—See Appendix X1 for correcting the theoretical maximum specific gravity when measurements are made at temperatures other than 25°C (77°F).

14. CALCULATION

14.1. Calculate the theoretical maximum specific gravity (G_{mm}) of the sample at 25°C (77°F) as follows:

14.1.1. *Mass Determination in Water:*

$$\text{theoretical maximum specific gravity} = \frac{A}{A - C} \quad (2)$$

where:

A = mass of the oven-dry sample in air, g; and

C = mass of the sample in water at 25°C (77°F), g.

14.1.2. *Mass Determination in Air:*

$$\text{theoretical maximum specific gravity} = \frac{A}{A + D - E} \quad (3)$$

where:

A = mass of the oven-dry sample in air, g;

D = mass of the container filled with water at 25°C (77°F), g; and

E = mass of the container filled with the sample and water at 25°C (77°F), g.

14.1.3. *Large-Size Plastic Pycnometer Determinations:*

14.1.3.1. If the test temperature is between 22.2 and 26.7°C (72 and 80°F), Equation 3 may be used to calculate specific gravity (G_{mm}) within a minor amount of error due to thermal effects (0.001 points or less).

14.1.3.2. If the test temperature differs significantly from 25°C (77°F), correct for thermal effects as follows:

$$\text{specific gravity} = \frac{A}{(A + F) - (G + H)} \times \frac{dw}{0.9970} \quad (4)$$

where:

A = mass of the oven-dry sample in air, g;

F = mass of the pycnometer filled with water at the test temperature (Figure 3), g;

G = mass of the pycnometer filled with water and the sample at the test temperature, g;

H = correction for thermal expansion of asphalt (Figure 5), g;

dw = density of water at the test temperature, Curve D in Figure 6, Mg/m^3 ; and

0.9970 = density of water at 25°C (77°F), Mg/m^3 .

The ratio ($dw/0.9970$) is Curve R in Figure 6.

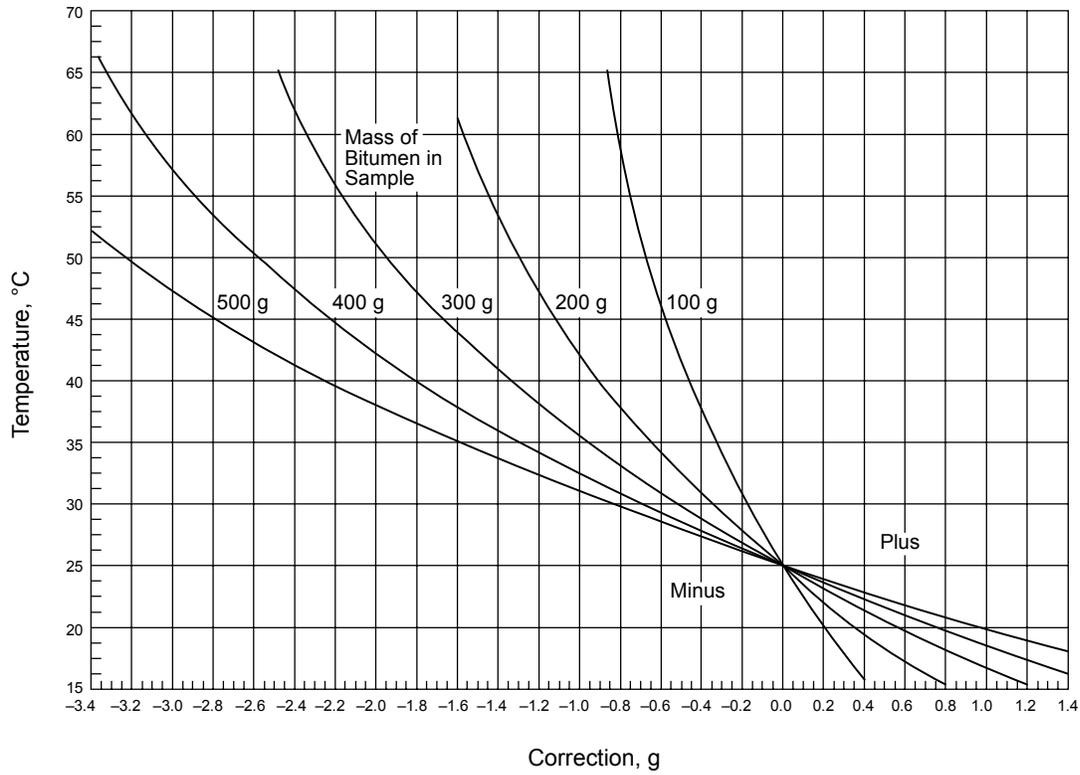


Figure 5—Correction Curves for Expansion of Asphalt, H , in Equation 4

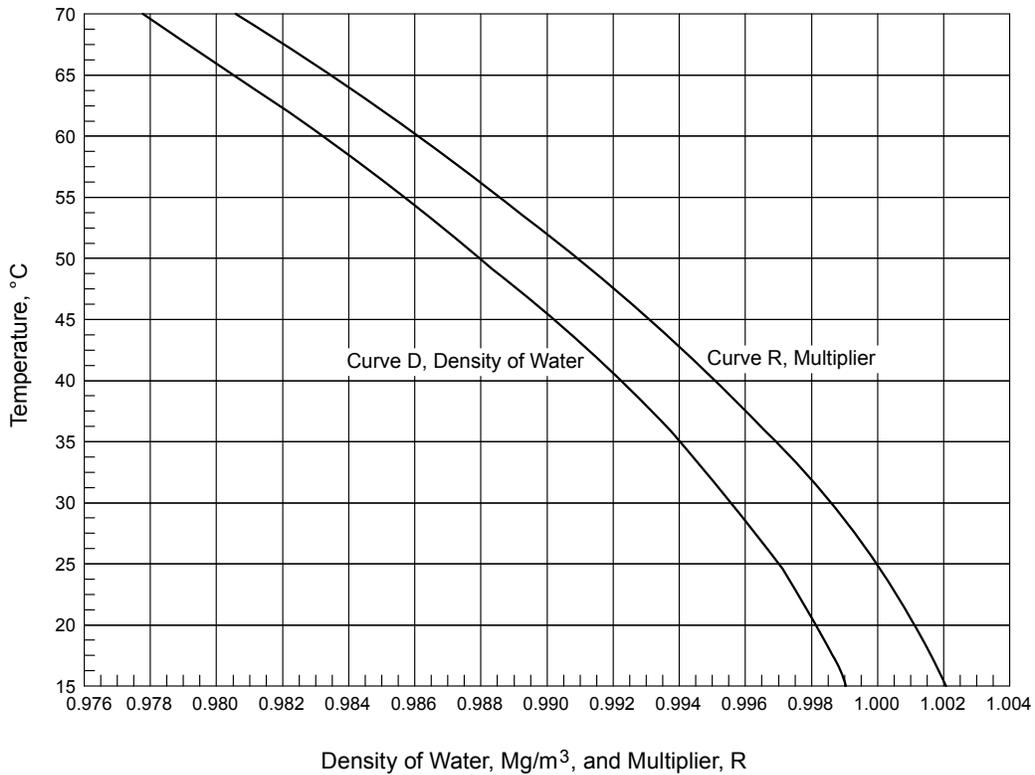


Figure 6—Curves D and R for Equation 4

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Note 10—This general procedure for correcting for thermal effects should also be applicable to corresponding measurements made with other suitable containers.

Note 11—When samples are tested a portion at a time, differences between the maximum specific gravities for each portion should be within the precision statements listed in Section 17. If the values are within the precision statements, the specific gravities for each portion shall be averaged. If the values are outside the precision statements, the test shall be performed again.

14.2. *Theoretical maximum density (G_{mm}) at 25°C (77°F):*

14.2.1. Calculate the corresponding theoretical maximum density (G_{mm}) at 25°C (77°F) as follows:

Theoretical maximum density at 25°C (77°F) = theoretical maximum specific gravity × 997.1 kg/m³ in SI units.

or

Theoretical maximum density at 25°C (77°F) = theoretical maximum specific gravity × 62.245 lb/ft³ in inch-pound units.

where:

The density of water at 25°C (77°F) = 997.1 kg/m³ in SI units or 62.245 lb/ft³ in inch-pound units.

15. SUPPLEMENTAL PROCEDURE FOR MIXTURES CONTAINING POROUS AGGREGATE

Note 12—Experiments indicate that this supplemental procedure has an insignificant effect on the test results if the HMA contains individual aggregate with a water absorption below 1.5 percent.

15.1. If the pores of the aggregates are not thoroughly sealed by an asphalt film, they may become saturated with water during the application of vacuum. To determine if this condition has occurred, proceed as follows after completing Section 13.1 or 13.2. Drain the water from the sample. To prevent the loss of fine particles, decant the water through a towel held over the top of the container. Break several large pieces of aggregate and examine the broken surfaces for wetness.

15.2. If the aggregate has absorbed water, spread the sample before an electric fan to remove the surface moisture. Determine the mass at 15-min intervals, and when the loss in mass is less than 0.05 percent for this interval, the sample may be considered to be surface dry. This procedure requires about 2 h and shall be accompanied by intermittent stirring of the sample. Break conglomerations of HMA by hand. Take care to prevent loss of the HMA particles.

15.3. To calculate the specific gravity of the sample, substitute the final surface-dry mass determined in Section 15.2 for A in the denominator of Equation 2 or 3 as appropriate.

16. REPORT

16.1. *Report the following information:*

16.1.1. G_{mm} and density of the HMA to the nearest 0.001 for specific gravity or nearest 1 kg/m³ (0.1 lb/ft³) for density as follows: sp gr 25/25°C (77/77°F) or density at 25°C (77°F);

16.1.2. Type of HMA;

16.1.3. Size of the sample;

- 16.1.4. Number of samples;
- 16.1.5. Type of container; and
- 16.1.6. Type of procedure.

17. PRECISION

- 17.1. Criteria for judging the acceptability of specific gravity test results obtained by this test method are given in the following table:

Table 2—Precision Estimates

| Test and Type Index | Standard Deviation (1s) | Acceptable Range of Two Results (d2s) |
|---|-------------------------|---------------------------------------|
| Test results obtained without use of Section 15 | | |
| Method A ^a | | |
| Single-operator precision | 0.0051 | 0.014 |
| Multilaboratory precision | 0.0084 | 0.024 |
| Method B ^b | | |
| Single-operator precision | 0.0064 | 0.018 |
| Multilaboratory precision | 0.0103 | 0.029 |

^a Basis of estimate: 1 replicate, 1 material, 344 laboratories.

^b Basis of estimate: 1 replicate, 1 material, 134 laboratories.

- 17.2. The figures given in Column 2 are the standard deviations that have been found to be appropriate for the conditions of the test described in Column 1. The figures given in Column 3 are the limits that should not be exceeded by the difference between the results of two properly conducted tests. Multilaboratory precision has not been verified for 4500-mL or larger pycnometers.
- 17.3. The values in Column 3 are the acceptable range for two tests. When more than two results are being evaluated, the range given in Column 3 must be increased. Multiply the standard deviation(s) in Column 2 by the multiplier given in Table 1 of ASTM C670 for the number of actual tests.
- Example for three tests: $0.004 \times 3.3 = 0.013$.
- Additional guidance and background is given in ASTM C670.

APPENDIX

(Nonmandatory Information)

X1. THEORETICAL MAXIMUM SPECIFIC GRAVITY FOR LOOSE HMA

X1.1. *Scope:*

X1.1.1. This appendix has two objectives:

X1.1.1.1. To indicate a method for correcting the theoretical maximum specific gravity to 25°C (77°F) when measurements are made at temperatures other than 25°C (77°F).

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X1.1.1.2. To indicate the range of temperature in °C above or below 25°C (77°F) within which no temperature correction is required, because the measured theoretical maximum specific gravity values are shown to be 0.0004 or less away from the value determined at 25°C (77°F).

X1.2. *Indicated Values:*

X1.2.1. The following example values are indicated for the theoretical maximum specific gravity of a loose HMA sample:

X1.2.1.1. Mass of the loose HMA sample = 1251.3 g.

X1.2.1.2. Volume of the loose HMA sample at 25°C (77°F) = 492.77 mL.

X1.2.1.3. Asphalt binder content = 5.0 percent of total mix.

X1.2.1.4. Specific gravity of the asphalt at 25°C (77°F) = 1.029.

X1.2.1.5. Combined bulk specific gravity of the aggregate = 2.714.

X1.2.1.6. Cubical coefficient of expansion of the asphalt binder at 20°C (68°F) = 6.2×10^{-4} mL/mL/°C (ASTM D4311/D4311M).

X1.2.1.7. Cubical coefficient of expansion of the aggregate at 20°C (68°F) = 2.2×10^{-5} mL/mL/°C.²

X1.3. *Basis of Calculation for 1 g of Loose HMA at 20°C (68°F):*

X1.3.1. Mass of the asphalt binder = 0.05 g.

X1.3.2. Volume of the asphalt binder = $0.05/1.029 = 0.0486$ mL.

X1.3.3. Mass of the aggregate = 0.95 g.

X1.3.4. Volume of the aggregate = $0.95/2.714 = 0.3500$ mL.

X1.3.5. Volume of the asphalt binder plus aggregate in 1 g of loose HMA at 20°C (68°F) = $0.0486 + 0.3500 = 0.3986$ mL.

X1.4. *Basis of Calculation for Volume Change of 1 g of Loose HMA for 1°C (2°F) from 20°C (68°F):*

X1.4.1. Volume change for the asphalt binder = $6.2 \times 10^{-4} \times 0.0486 = 0.3013 \times 10^{-4}$ mL = 3.0130×10^{-5} mL.

X1.4.2. Volume change for the aggregate = $2.2 \times 10^{-5} \times 0.3500 = 0.77 \times 10^{-5}$ mL.

X1.4.3. Volume change for 1 g of loose HMA for 1°C (2°F) change in temperature from 20°C (68°F) = $3.0130 \times 10^{-5} + 0.7700 \times 10^{-5} = 3.7830 \times 10^{-5}$ mL.

X1.5. *Volume Correction:*

X1.5.1. For a difference in water temperature of 1°C (2°F) above or below 20°C (68°F), a correction to the volume of water displaced by 1 g of loose HMA can be made by the following equation:

$$\text{correction} = \Delta T \times K_T \times V_T \text{ mL} \quad (X1.1)$$

where:

ΔT = 1°C (2°F);

K_T = volume change of 1 g of loose HMA for a 1°C (2°F) change in temperature above or below 20°C (68°F) = 3.7830×10^{-5} mL; and

V_T = volume of water for a corresponding 1251.3-g mass of loose HMA at a test temperature of 20°C (68°F) = 492.77 mL.

Substituting these values into the equation gives the following:

$$\text{Correction} = 1 \times 3.7830 \times 10^{-5} \times 492.77 = 0.01864 \text{ mL/g at } 20^\circ\text{C (68}^\circ\text{F)}.$$

X1.6. Table X1.1 illustrates an example of the influence of temperature corrections. For a measured volume and a given mass of HMA tested at specific temperatures, this table relates these influences to the specific gravity of the HMA.

Table X1.1—Influence of Temperature Corrections to a Measured Volume at 20°C of a Given Mass of Loose Paving Mixture, to Provide the Required Theoretical Maximum Specific Gravity at 25°C

| Temperature, °C | Volume of HMA at 20°C (68°F), mL | Volume Correction for Temp Change | Corrected Volume of HMA at 20°C (68°F), mL | Mass of HMA, g | Specific Gravity of HMA |
|-----------------|----------------------------------|-----------------------------------|--|----------------|-------------------------|
| 1 | 2 | 3 | 4 = 2 + 3 | 5 | 6 = 5/4 |
| 31 | 492.77 | 0.2046 | 492.975 | 1251.3 | 2.5383 |
| 30 ^a | 492.77 | 0.1860 | 492.956 | 1251.3 | 2.5384 |
| 29 ^a | 492.77 | 0.1674 | 492.937 | 1251.3 | 2.5385 |
| 28 ^a | 492.77 | 0.1488 | 492.919 | 1251.3 | 2.5386 |
| 27 ^a | 492.77 | 0.1302 | 492.900 | 1251.3 | 2.5386 |
| 26 ^a | 492.77 | 0.1116 | 492.882 | 1251.3 | 2.5387 |
| 25 ^a | 492.77 | 0.0930 | 492.863 | 1251.3 | 2.5388 |
| 24 ^a | 492.77 | 0.0744 | 492.844 | 1251.3 | 2.5389 |
| 23 ^a | 492.77 | 0.0558 | 492.826 | 1251.3 | 2.5390 |
| 22 ^a | 492.77 | 0.0372 | 492.807 | 1251.3 | 2.5391 |
| 21 ^a | 492.77 | 0.0186 | 492.789 | 1251.3 | 2.5392 |
| 20 | 492.77 | 0.0000 | 492.772 | 1251.3 | 2.5393 |
| 19 | 492.77 | -0.0186 | 492.751 | 1251.3 | 2.5394 |

^a Range less than 0.0005.

Notes: Strictly speaking, the above table shows that the specific gravity for this particular mix, as measured at 20°C (68°F), just fails to meet the corrected theoretical maximum specific gravity at 25°C (77°F), 2.5388 versus 2.5393, that is, by 0.0005, and that a temperature correction would be required. If the measurement for volume had been made at 21°C (70°F), the table indicates that no temperature correction would have been necessary, because the measurement at 21°C (70°F) would have satisfied the theoretical maximum specific gravity at 25°C (77°F), 2.5388 versus 2.5392, a difference of less than 0.0005.

¹ Sargent Welch, 39745 Gauge-Vacuum, Mercury Prefilled (or equivalent).

² Krebs and Walker, *Highway Materials*, McGraw-Hill, Inc., 1971, p. 274.