



Designation: D 2041 – 03

## Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures<sup>1</sup>

This standard is issued under the fixed designation D 2041; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the Department of Defense.*

### 1. Scope

1.1 This test method covers the determination of the theoretical maximum specific gravity and density of uncompacted bituminous paving mixtures at 25°C (77°F).

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *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 ASTM Standards:

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials<sup>2</sup>

D 979 Practice for Sampling Bituminous Paving Mixtures<sup>3</sup>

D 4753 Guide for Evaluating, Selecting, and Specifying Balances and Scales for Use in Soil, Rock, and Construction Materials Testing<sup>4</sup>

E 1 Specification for ASTM Thermometers<sup>5</sup>

E 12 Terminology Relating to Density and Specific Gravity of Solids, Liquids, and Gases<sup>6</sup>

### 3. Terminology

3.1 The terms “specific gravity” and “density” used in this test method are in accordance with Terminology E 12.

#### 3.2 Definitions of Terms Specific to This Standard:

3.2.1 *density, as determined by this test method*—the mass of a cubic metre of the material at 25°C (77°F) in SI units.

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

3.2.3 *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 paving mixture in the loose condition is placed in a tared vacuum vessel. Sufficient water at a temperature of 25°C (77°F) is added to completely submerge the sample. Vacuum is gradually applied to reduce the residual pressure in the vacuum vessel to 4 kPa (30 mm of Hg) or less and then held for 15 ± 2 min. At the end of the vacuum period, the vacuum is gradually released. The volume of the sample of paving mixture is obtained by immersing the vacuum container with the sample in a water bath and weighing or by filling the vacuum container level full of water and weighing in air. Both the temperature and mass are measured at this time. From these mass and volume measurements, the specific gravity or density at 25°C is calculated.

### 5. Significance and Use

5.1 The theoretical maximum specific gravities and densities of bituminous paving mixtures are fundamental properties whose values are influenced by the composition of the mixture in terms of types and amounts of aggregates and bituminous materials.

5.1.1 Maximum specific gravity is used (1) in the calculation of air voids in the compacted bituminous paving mixture, (2) in calculating the amount of bitumen absorbed by the aggregate, and (3) to provide target values for the compaction of paving mixtures.

### 6. Apparatus

#### 6.1 Containers:

6.1.1 *Vacuum Bowls*—Either a metal or plastic bowl with a diameter of approximately 180 to 260 mm (7 to 10.25 in.) and a bowl height of at least 160 mm (6.3 in.) shall be equipped with a transparent cover fitted with a rubber gasket and a connection for the vacuum line. Both the bowl and cover should be sufficiently stiff to withstand the applied vacuum

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<sup>2</sup> *Annual Book of ASTM Standards*, Vol 04.02.

<sup>3</sup> *Annual Book of ASTM Standards*, Vol 04.03.

<sup>4</sup> *Annual Book of ASTM Standards*, Vol 04.08.

<sup>5</sup> *Annual Book of ASTM Standards*, Vol 14.03.

<sup>6</sup> Discontinued, replaced by Terminology E 1547. See 1995 *Annual Book of ASTM Standards*, Vol 15.05.

pressure without visibly deforming. The hose connection shall be covered with a small piece of fine wire mesh to minimize the loss of any fine material.

NOTE 1—The transparent cover allows observation of the release of air bubbles.

6.1.2 *Vacuum Flask for Weighing in Air Only*, a thick-walled volumetric glass flask with a capacity of approximately 4000 mL, fitted with a rubber stopper with a connection for the vacuum line. The hose connection in the flask should be covered with a small piece of fine wire mesh to minimize the loss of any fine material

6.2 *Balance*, capable of being read to the nearest 0.1 g and conforming to the requirements of Specification D 4753, Class GP2. If underwater measurements will be taken, then the balance shall be equipped with a suitable suspension apparatus and holder to permit weighing the sample while suspended from the center of the scale.

6.3 *Vacuum Pump or Water Aspirator*, capable of evacuating air from the vacuum container to a residual pressure of 4.0 kPa (30 mm of Hg) or less.

6.3.1 When a vacuum pump is used, a suitable trap shall be installed between the vacuum vessel and vacuum source to reduce the amount of water vapor entering the vacuum pump.

6.4 *Residual Pressure Manometer or Calibrated Absolute Pressure Gage*—This manometer or calibrated absolute pressure gage shall be used to confirm the specified pressure is applied to the container and shall be capable of measuring residual pressure to 4.0 kPa (30 mm of Hg) or less. It is to be connected at the end of the vacuum line using an appropriate tube and either a “T” connector on the top of the container or by using a separate opening (from the vacuum line) in the top of the container to attach the hose. To avoid damage, the manometer or gage itself is not to be situated on top of the vessel but adjacent to it.

NOTE 2—Residual pressure in the vacuum vessel in millimetres of mercury is the difference in the height of mercury.

6.5 *Manometer or Vacuum Gage*, suitable for measuring the vacuum being applied at the source of the vacuum. This device can be connected directly to the vacuum source or be in the vacuum line close to the source.

NOTE 3—The vacuum leg of a residual pressure manometer occasionally acquires one or more air bubbles that introduce error into the residual pressure reading. The additional vacuum gage or manometer provides a means to quickly detect differences between the two vacuum measurements.

6.6 *Thermometers*—Calibrated liquid-in-glass thermometers of suitable range with subdivisions and maximum scale error of 0.5°C (0.9°F), or any other thermometric device of equal accuracy, precision, and sensitivity shall be used. Thermometers shall conform to the requirements of Specification E 1.

6.7 *Water Bath*, capable of maintaining, by any means, a constant temperature between 20 and 30°C (70 to 85°F). The water bath must be suitable for immersion of the suspended container with its deaerated sample.

6.8 *Bleeder Valve*, attached to the vacuum train to facilitate both the adjustment of the vacuum being applied to the vacuum vessel and the slow release of vacuum pressure.

6.9 *Mechanical Agitation Device*, capable of applying a gentle but consistent agitation of the sample. This device shall be equipped with a means of firmly anchoring the container so that it does not move on the surface of the device.

NOTE 4—If stripping of asphalt is a problem, the device can be equipped with a speed control.

6.10 *Oven*, capable of maintaining a temperature of 110 ± 5°C (230 ± 9°F). This oven is needed when samples other than laboratory prepared mixtures using oven-dry aggregate are tested.

## 7. Sampling

7.1 Obtain the sample in accordance with Practice D 979.

7.2 The size of sample shall be as follows:

| Nominal Maximum Aggregate Size, mm | Minimum Sample Size, g |
|------------------------------------|------------------------|
| 37.5 or greater                    | 5000                   |
| 19 to 25                           | 2500                   |
| 12.5 or smaller                    | 1500                   |

7.3 Sample sizes greater than about two thirds of the volume of the container shall be tested in portions with none of the portions tested being less than 1250 g.

## 8. Calibration of Containers

8.1 *Bowls*—Calibrate the container by accurately determining the mass of the container immersed in water at 25 ± 0.5°C (77 ± 0.9°F). Designate this mass as *B*.

8.1.1 If the bowl is used for weighing in air, place the volumetric lid on the bowl while under water. Remove the water-filled bowl with the lid in place and dry prior to determining the combined mass of the bowl, lid, and water. Repeat three times and average the results. Designate the average mass as *D*.

8.2 *Flasks*—Calibrate the volumetric flask by accurately determining the mass of the flask filled with water at a temperature of 25 ± 0.5°C (77 ± 0.9°F). Designate this mass as *D*. Accurate filling of the flask shall be ensured by the use of a glass cover plate or similar smooth, flat transparent plate.

## 9. Procedure

9.1 If the paving mixture has been prepared in a laboratory using oven-dry aggregates, proceed to 9.2. Any other sample needs to be dried to a constant mass (mass repeats within 0.1 % for consecutive 15-min weighings) at a temperature of 105 ± 5°C (221 ± 9°F).

9.2 Once the sample is dry and while it is still warm, separate the particles of the sample of paving mixture by hand, taking care to avoid fracturing the aggregate, so that the particles of the fine aggregate portion are not larger than about 6 mm. Cool the sample to room temperature. Additional separation of the mixture is needed so that the particles of the fine aggregate portion are not larger than about 6 mm. Place the sample directly into the tared bowl or volumetric flask. Do not use a container within a container. Weigh the container with the sample and designate the net mass (mass of sample only) as *A*.

9.3 Add sufficient water at a temperature of approximately 25°C (77°F) to cover the sample completely. Place the cover (bowls) or stopper (flask) on the container.

9.4 Place the container with the sample and water on a mechanical agitation device and anchor it to the surface of the

device. Start the agitation and immediately begin to remove air trapped in the sample by gradually increasing the vacuum pressure until the residual pressure manometer reads  $3.7 \pm 0.3$  kPa ( $27.5 \pm 2.5$  mm) of Hg. The vacuum should be achieved within 2 min. Once the vacuum is achieved, continue the vacuum and agitation for  $15 \pm 2$  min.

9.5 Gradually release the vacuum pressure using the bleeder valve and proceed with one of the following determinations:

9.5.1 *Weighing in Water*—Suspend the bowl (without lid) and contents in water for  $10 \pm 1$  min, then determine the mass. Measure and record the temperature of the water in the bath. Designate the mass under water of the bowl and sample as *C*.

9.5.2 *Weighing in Air (Bowl)*—Slowly submerge the bowl and sample in a water bath for  $10 \pm 1$  min. The lid shall also be placed in the water bath at the same time. Slide the lid onto the bowl without removing from the water so as to avoid entrapping any air, then firmly press the lid down on the bowl. Remove the bowl with the lid in place from the water bath. Carefully dry the bowl and lid. Determine the mass of the bowl, sample, and lid. Measure and record the temperature of the water in the bowl. Repeat this procedure a second time by removing the lid and placing both the lid and the bowl back in the water. It is not necessary to wait the 10 minutes before taking the second reading. If the weight varies by more than 1.0 g, repeat the procedure until any two weights are within 1.0 g. Designate the mass of the bowl, lid, water, and sample as *E*.

9.5.3 *Weighing in Air (Flask)*—Slowly fill the flask with water taking care not to introduce air into the sample. Place the flask in a water bath for  $10 \pm 1$  min to stabilize the temperature without submerging the top of the flask. Measure and record the temperature of the water in the flask. Remove the thermometers and completely fill the flask using a cover plate, taking care not to entrap air beneath the cover plate. The cover plate shall be the same one used during the calibration of the flask. Wipe any moisture from the exterior of the container and cover plate. Determine the mass of the flask, plate, and its contents completely filled with water. Designate this mass as *E*.

## 10. Calculation

10.1 Calculate the maximum specific gravity of the sample as follows:

10.1.1 *Bowls Used Under Water Determination:*

$$G_{mm} = \frac{A}{A - (C - B)} \quad (1)$$

where:

- $G_{mm}$  = maximum specific gravity of the mixture,
- A* = mass of dry sample in air, g,
- B* = mass of bowl under water, g, and
- C* = mass of bowl and sample under water, g.

10.1.2 *Bowl in Air Determination:*

$$G_{mm} = \frac{A}{A + D - E} \quad (2)$$

where:

- $G_{mm}$  = maximum specific gravity of the mixture,
- A* = mass of dry sample in air, g,
- D* = mass of lid and bowl with water at 25°C (77°F), g, and

*E* = mass of lid, bowl, sample, and water at 25°C (77°F), g.

10.1.3 *Flask Determination:*

$$G_{mm} = \frac{A}{A + D - E} \quad (3)$$

where:

- $G_{mm}$  = maximum specific gravity of the mixture,
- A* = mass of dry sample in air, g,
- D* = mass of cover plate and flask filled with water at 25°C (77°F), g, and
- E* = mass of flask, cover plate, sample, and water at 25°C (77°F), g.

10.2 If the sample was tested in several portions, report the weighted average maximum specific gravity for all portions tested.

10.3 If the water temperature was not 25°C (77°F), multiply the maximum specific gravity by the appropriate density correction factor (multiplier) from Table 1 or Table 2.

## 11. Supplemental Procedure for Mixtures Containing Porous Aggregate

11.1 If the pores of the aggregates are not thoroughly sealed by the bituminous film, they may become saturated with water during the vacuum procedure. To determine if this has occurred, proceed as follows after completing the procedure in accordance with 9.5.1, 9.5.2, or 9.5.3.

11.1.1 Drain the water from the container. To prevent the loss of fine particles, decant the water through a 75 µm (No. 200) sieve.

11.1.2 Break several of the large pieces of aggregate and examine the broken surfaces for wetness. If there is any doubt as to whether the mix has absorbed water, proceed with this procedure in order to determine if this correction is needed.

11.2 If aggregate has absorbed water, spread the sample on a flat tray with a nonabsorptive surface and place in front of a fan to remove surface moisture. Break agglomerations of mixture by hand. Stir the sample intermittently in such a way that the aggregate particles are rolled over rather than simply moved horizontally on the tray. This process takes about 2 h. Take care to prevent the loss of particles of mixture.

11.3 Weigh the tray and sample at 15-min intervals. When the loss in mass is less than 0.05 % for this interval, the sample may be considered to be surface dry.

11.4 Substitute the final surface dry mass for *A* and use this value in the denominator of equations shown in Section 10.

**TABLE 1 Temperature-Density Correction Factors for °C**

| Temperature | Multiplier | Temperature | Multiplier |
|-------------|------------|-------------|------------|
| 21.0        | 1.000951   | 25.5        | 0.999870   |
| 21.5        | 1.000840   | 26.0        | 0.999738   |
| 22.0        | 1.000728   | 26.5        | 0.999604   |
| 22.5        | 1.000613   | 27.0        | 0.999466   |
| 23.0        | 1.000495   | 27.5        | 0.999327   |
| 23.5        | 1.000375   | 28.0        | 0.999186   |
| 24.0        | 1.000253   | 28.5        | 0.999042   |
| 24.5        | 1.000127   | 29.0        | 0.998897   |
| 25.0        | 1.000000   | 29.5        | 0.998748   |

**TABLE 2 Temperature-Density Correction Factors for °F**

| Temperature | Multiplier | Temperature | Multiplier |
|-------------|------------|-------------|------------|
| 70          | 1.000929   | 78          | 0.999844   |
| 71          | 1.000795   | 79          | 0.999711   |
| 72          | 1.000682   | 80          | 0.999549   |
| 73          | 1.000543   | 81          | 0.999411   |
| 74          | 1.000423   | 82          | 0.999243   |
| 75          | 1.000277   | 83          | 0.999100   |
| 76          | 1.000152   | 84          | 0.998926   |
| 77          | 1.000000   | 85          | 0.008778   |

| Test and Type Index   | Standard Deviation, 1s | Acceptable Range of Two Test Results, d2s |
|---|------------------------|---|
| Test results obtained without use of Section 11: <sup>A</sup>                     |                        |   |
| Single-operator precision   | 0.0080                 | 0.023                                     |
| Multilaboratory precision   | 0.0160                 | 0.044                                     |
| Test results obtained with use of Section 11 (for Bowl Method only): <sup>B</sup> |                        |   |
| Single-operator precision   | 0.0064                 | 0.018                                     |
| Multilaboratory precision   | 0.0193                 | 0.055                                     |

<sup>A</sup> Basis of estimate: analysis of paired test results from 165 to 337 laboratories participating in the AASHTO Materials Reference Laboratory (AMRL) Proficiency Sample Program.

<sup>B</sup> Basis of estimate: 2 replicates, 7 materials, 20 laboratories.

## 12. Report

12.1 Report the following information:

- 12.1.1 Maximum specific gravity,  $G_{mm}$ , to the third decimal place.
- 12.1.2 Type of mixture.
- 12.1.3 Size of sample.
- 12.1.4 Number of samples.
- 12.1.5 Type of container.
- 12.1.6 Type of procedure.

## 13. Precision

13.1 Criteria for judging the acceptability of specific gravity test results obtained by this test method are given as follows:

13.2 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.

13.3 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 Practice C 670 for the number of actual tests.

$$\text{Example for three tests: } 0.0040 \times 3.3 = 0.0132 \quad (4)$$

Additional guidance and background is given in Practice C 670.

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