Pavement Materials & Design

ASTM D2041-11

Density of Bituminous Paving Mixtures(G_{mm})

اختبار الكثافة الظاهرية القصوى للخلطة الاسفلتية

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HMA Mix Design

Asphalt Mixtures Types

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What Is Asphalt Mixture

- Asphalt mixture is combination of asphalt cement and aggregate that will give long-lasting performance as part of the pavement structure

Image source: https://www.floridaridesonus.org/learning-center/asphalt-101/

Introduction

- The fundamental performance properties are not directly measured in a normal mix design;
  - *Therefore, asphalt content is selected on the basis of a measured volumetric parameter that best controls the pavement performance.*
- The volumetric properties are determined using
  - *the mass and/or volume measurements of a mixture and its constituent components (binder, aggregate, air).*
- Volumetric have historically provided a good indication of the mixture's probable performance during its service life

Mixture phases

Loose Mixture

Field

Laboratory

Image source: http://asphaltmagazine.com/fix-your-mix/ Image source: https://www.floridaridesonus.org/learning-center/asphalt-101/

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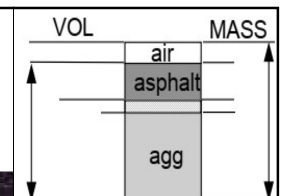
Mixture phases

Compacted Mixture



Field compacted

Laboratory compacted

Image source: http://asphaltmagazine.com/fix-your-mix/ Image source: https://www.floridaridesonus.org/learning-center/asphalt-101/

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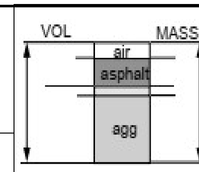
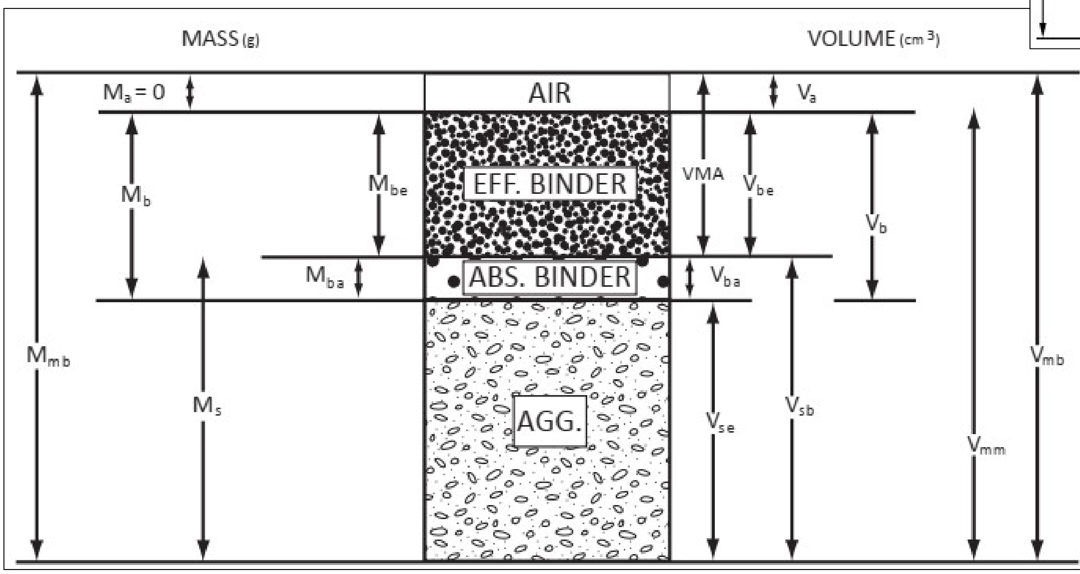
Volumetric analysis

Phase Diagram





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ASTM INTERNATIONAL

Designation: D2041/D2041M – 11

Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures[1]

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Terminology

3. Terminology

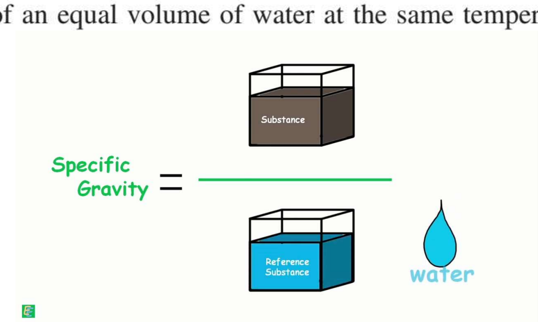
3.1 The terms "specific gravity" and "density" used in this test method are in accordance with Terminology E12.

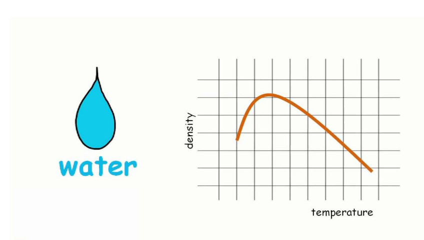
3.2 *Definitions of Terms Specific to This Standard:*

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

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.





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Scope

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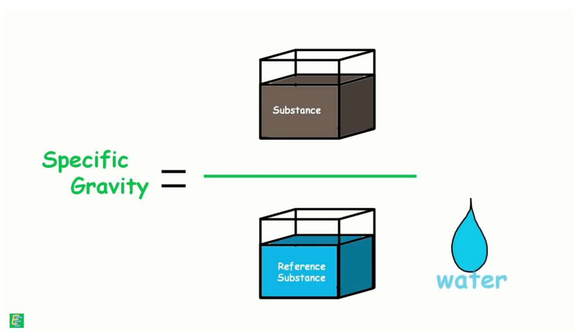
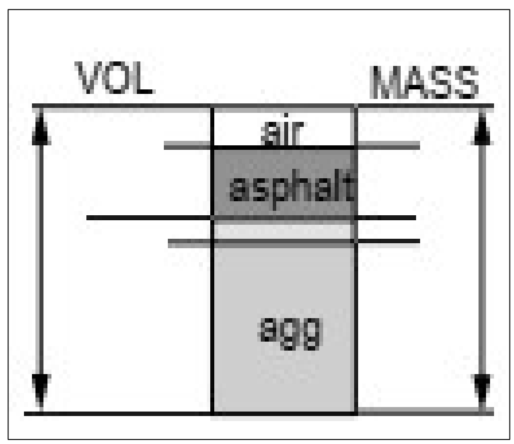
1. Scope

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].





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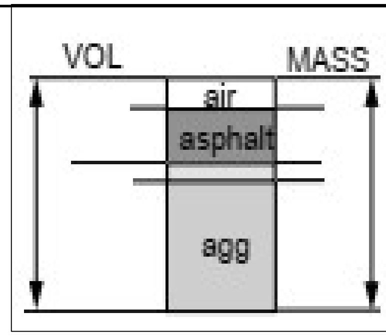
1. Scope

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 either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.2.1 Residual pressure measurements are shown in both the SI unit of kPa and the commonly used non-standard equivalent unit of "mm of Hg".

1.2.2 Measurements of volume and mass are only given in SI units because they are the only units typically used in practice when performing this test method.



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Referenced Documents

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2. Referenced Documents

2.1 *ASTM Standards:*[2]

C670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

D979 Practice for Sampling Bituminous Paving Mixtures

D3666 Specification for Minimum Requirements for Agencies Testing and Inspecting Road and Paving Materials

D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing

E1 Specification for ASTM Liquid-in-Glass Thermometers

E12 Terminology Relating to Density and Specific Gravity of Solids, Liquids, and Gases (Withdrawn 1996)[3]

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4. Summary of Test Method

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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 [77 °F] is calculated

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6. Apparatus

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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 in.] and a bowl height of at least 160 mm [6 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 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 2—The transparent cover allows observation of the release of air bubbles

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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

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6.2 *Balance,* capable of being read to the nearest 0.1 g and conforming to the requirements of Specification D4753, 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.

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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.

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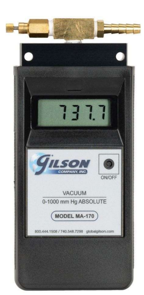
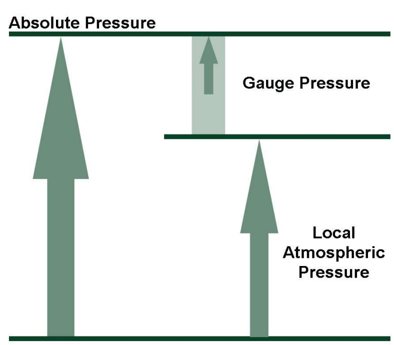
6.3.1 When a vacuum pump is used, a suitable trap shall be installed between the vacuum vessel and vacuum source to reduce the amount of water vapor entering the vacuum pump.

A safety trap is connected between the flask and the pump. This prevents the possible back up of water from the aspirator to contaminate the filtrate.

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.

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





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 4—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.

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6.6 *Thermometers*—Calibrated liquid-in-glass thermometers of suitable range with subdivisions and maximum scale error of 0.5°C [1°F], conforming to the requirements of Specification E1 or any other thermometric device of equal accuracy, precision, and sensitivity shall be used.

6.7 *Water Bath,* capable of maintaining, by any means, a constant temperature of 25 ± 1°C [77 ± 2°F]. The water bath must be suitable for immersion of the suspended container with its deaerated sample.

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

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

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6.10 *Oven,* capable of maintaining a temperature of 110 ± 5°C [230 ± 10°F]. This oven is needed when samples other than laboratory prepared mixtures using oven-dry aggregate are tested.

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7. Sampling

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7. Sampling

7.1 Obtain the sample in accordance with Practice D979.

7.2 The size of sample shall be as follows:

Nominal Maximum Aggregate Size, mm [in.]	Minimum Sample Size, g
37.5 [1 ½] or greater	5000
19 to 25 [3/4 to 1]	2500
12.5 [1/2] 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.

D979 Practice for Sampling Bituminous Paving Mixtures

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8. Calibration of Containers

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8.1 *Bowls*—Calibrate the container by accurately determining the mass of the container immersed in water at 25 ± 1°C [77 ± 2°F]. Designate this mass as *B*.

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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*.

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8.2 *Flasks*—Calibrate the volumetric flask by accurately determining the mass of the flask filled with water at a temperature of 25 ± 1°C [77 ± 2°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.

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9. Procedure

Basic General Steps

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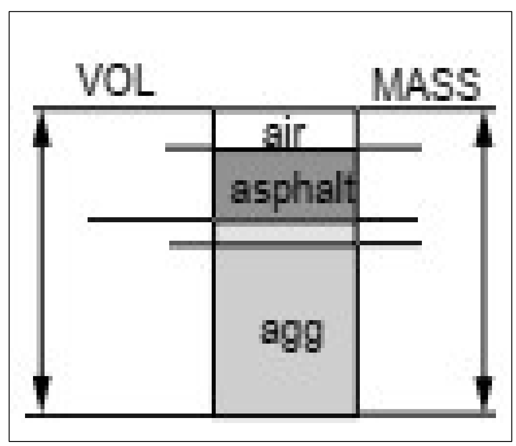

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9. Procedure

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 determinations) at a temperature of 110 ± 5°C [230± 10°F].

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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 [1/4 in.]. Cool the sample to room temperature. If separated particles adhere to each other once the sample has been cooled to room temperature, gently separate the particles of the fine aggregate portion so that they are not larger than about 6 mm [1/4 in.]. 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*.

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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.

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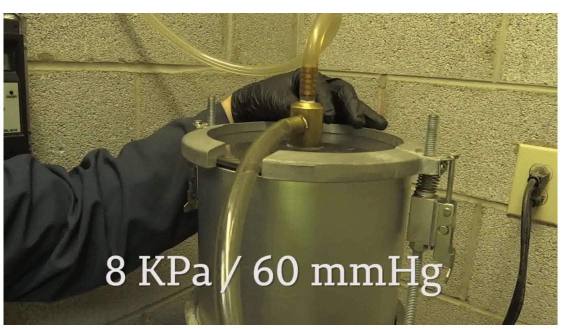
9.4 Place the container with the sample and water on a mechanical agitation device and anchor it to the surface of the device. Start the agitation and immediately begin to remove air trapped in the sample by gradually increasing the vacuum pressure until the residual pressure manometer reads 3.7 ± 0.3 kPa [27.5 ± 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 ± 2 min.



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

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9. Procedure

Method A: Weighing in Water

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9.5.1 *Weighing in Water*—Suspend the bowl (without lid) and contents in water for 10 ± 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*.

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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.

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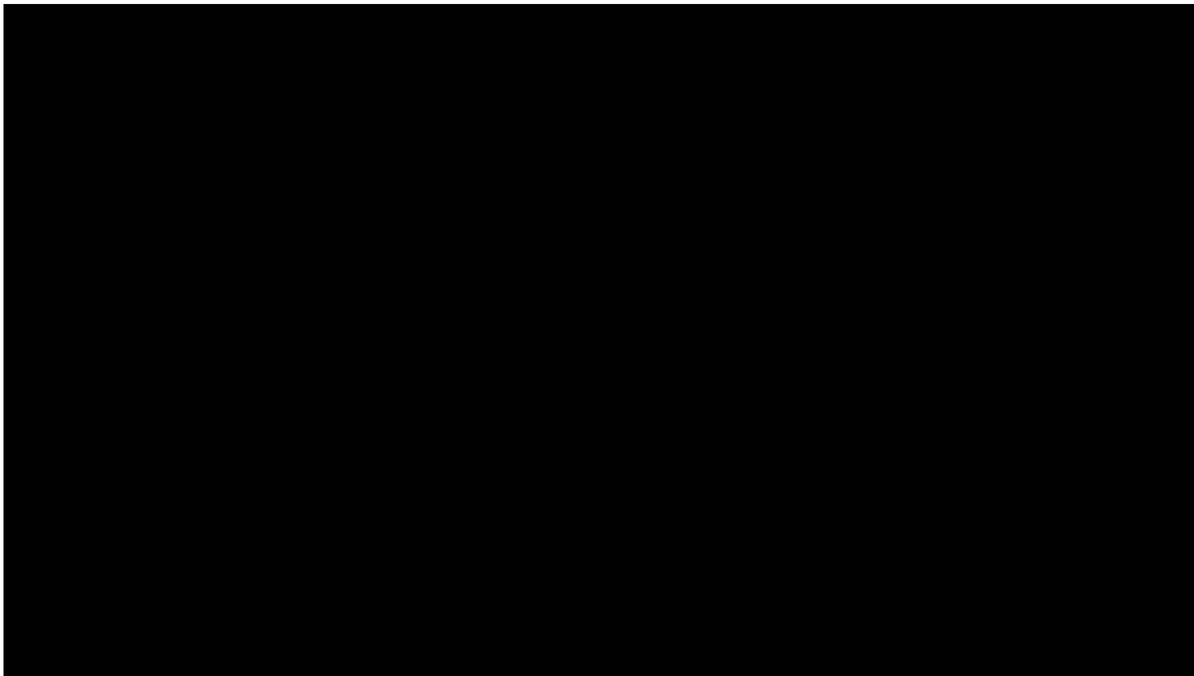

https://www.youtube.com/watch?v=YCyBRvEcdhI

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9. Procedure

Method B: Weighing in Air (Bowl)

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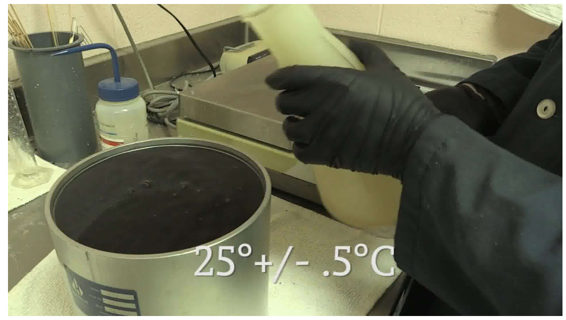
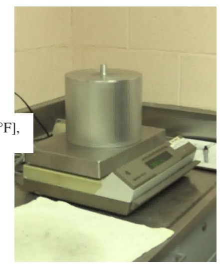
9.5.2 *Weighing in Air (Bowl)*—Slowly submerge the bowl and sample in the 25 ± 1°C [77 ± 2°F] bath, where it shall remain for 10 ± 1 min. The lid shall also be placed in the water bath at the same time. Slide the lid onto the bowl without removing from the water so as to avoid entrapping any air, then 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 mass varies by more than 1.0 g, repeat the procedure until any two mass readings are within 1.0 g. Designate the average mass of these two readings as "E; the mass of the bowl, lid, water, and sample."



and

E = mass of lid, bowl, sample, and water at 25°C [77°F], g.



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10.1.2 *Bowl in Air Determination:*

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

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.

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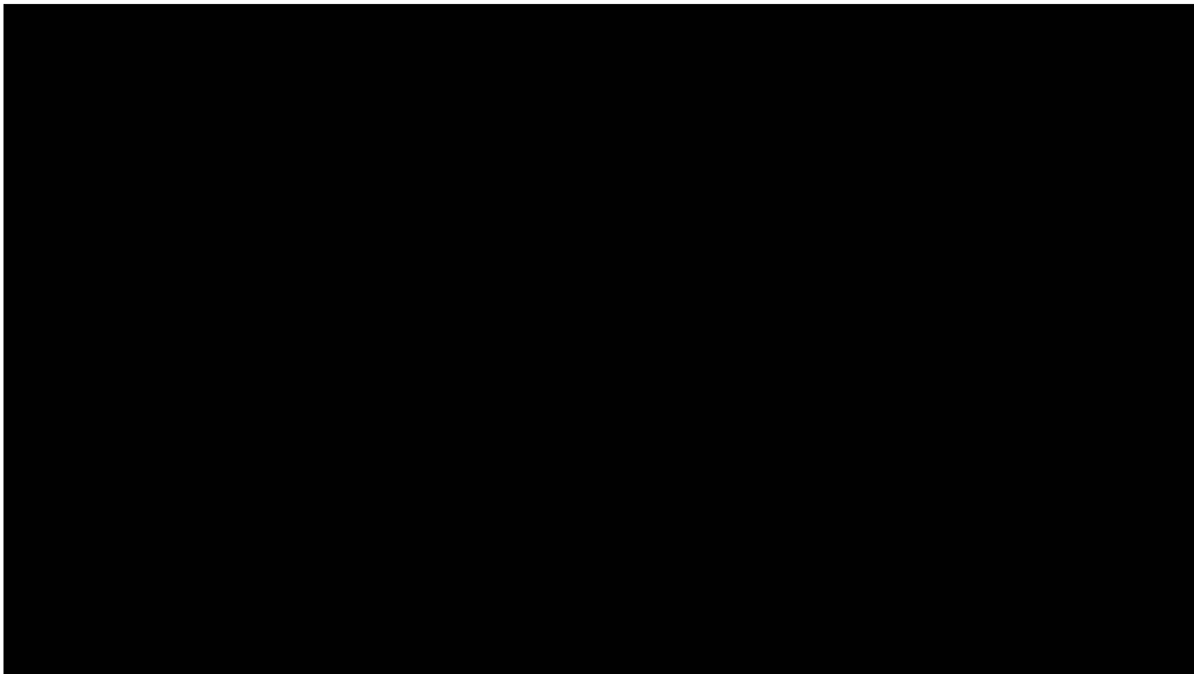

https://www.youtube.com/watch?v=YCyBRvEcdhI

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9. Procedure

Method C: Weighing in Air (Flask)

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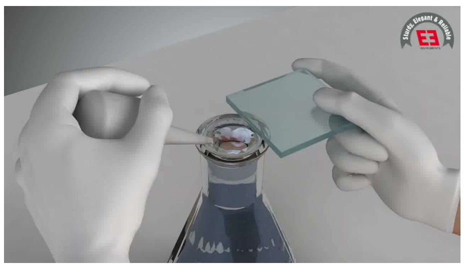
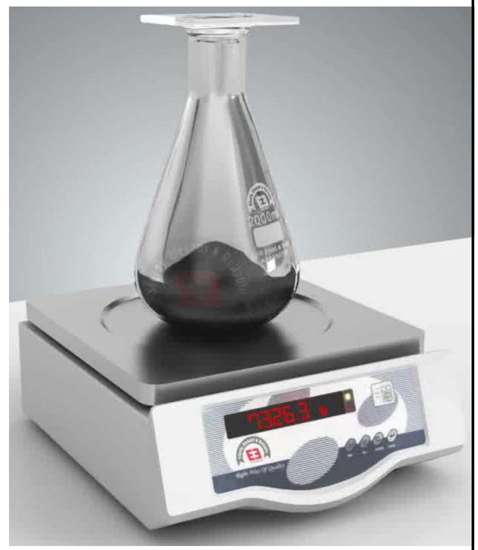
9.5.3 *Weighing in Air (Flask)*—Slowly fill the flask with water taking care not to introduce air into the sample. Place the flask in a water bath for 10 ± 1 min to stabilize the temperature without submerging the top of the flask. Measure and record the temperature of the water in the flask. Remove the thermometer 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*.





E = mass of flask, cover plate, sample, and water at 25°C [77°F], g.

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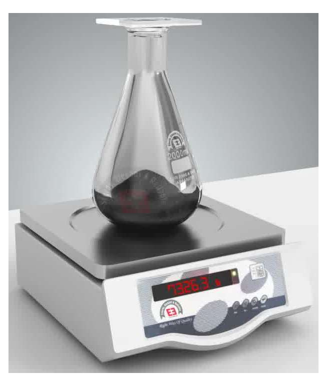
10.1.3 *Flask Determination:*

$$G_{mm} = \frac{A}{A + D - E} \tag{3}$$

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.

D =



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https://www.youtube.com/watch?v=Qn0WJJN5hXc

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12. Report

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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.

Typical values for theoretical maximum specific gravity range from approximately 2.400 to 2.700 depending on the aggregate specific gravity and asphalt binder content.

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5. Significance and Use

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5.1

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.

- The G_{mm} is a function with
  - *Percentage of aggregate (P_s)*
  - *Percentage of binder (P_b)*
  - *Effective specific gravity of aggregate (G_{se})*
  - *Specific gravity of binder (G_b)*

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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.

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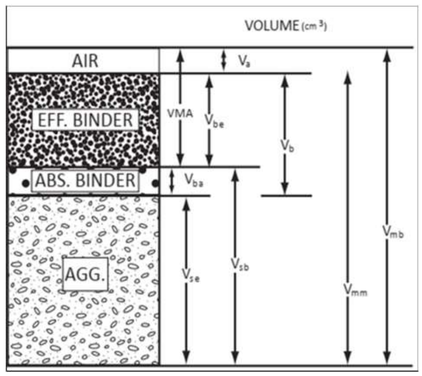
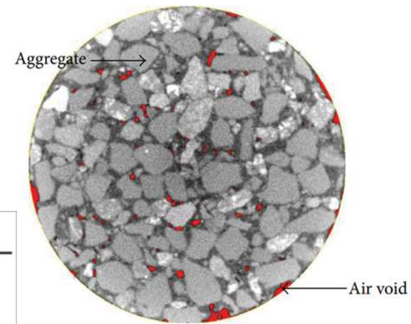
5.1.1 Maximum specific gravity is used

(1) in the calculation of air voids in the compacted bituminous paving mixture,

- Air Void
  - *The total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture,*
- Expressed as
  - *Percent of the total volume of the compacted paving mixture*
  - $V_a = 100 \times \frac{G_{mm} - G_{mb}}{G_{mm}}$





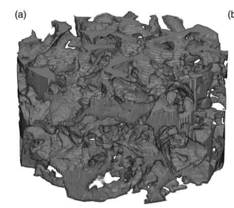


Figure 8. 3D connected air void structure of (a.) PA 11 and (b.) PA1

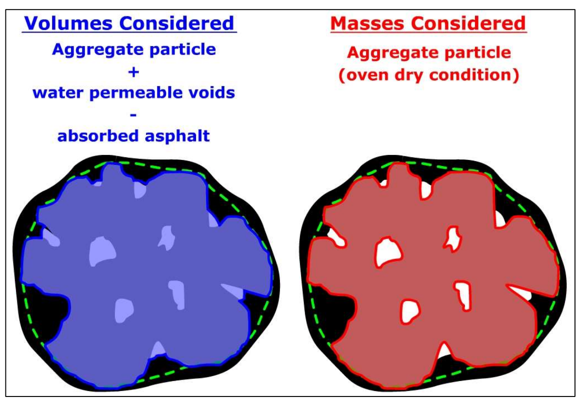
5.1.1 Maximum specific gravity is used

2) Determine the Effective Specific Gravity, G_{se}

- Effective Specific Gravity, G_{se}
  - The ratio of the mass in air of a unit volume of a permeable material (excluding voids permeable to asphalt) at a stated temperature to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature.
- The G_{se} is determined using Theoretical Maximum Specific Gravity G_{mm} later

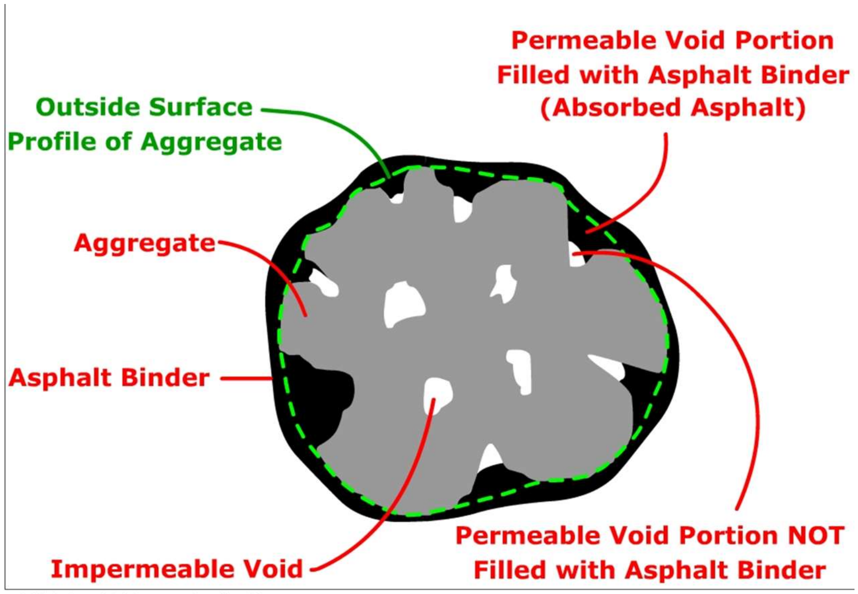
$$G_{se} = \frac{P_s}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}}$$

  - P_s = percentage of aggregate by total mix weight
  - P_b = percentage of binder by total mix weight
    - $P_s + P_b = 100$
  - G_{se} = effective specific gravity of aggregate
  - G_b = specific gravity of binder



5.1.1 Maximum specific gravity is used

3) in calculating the amount of bitumen absorbed by the aggregate



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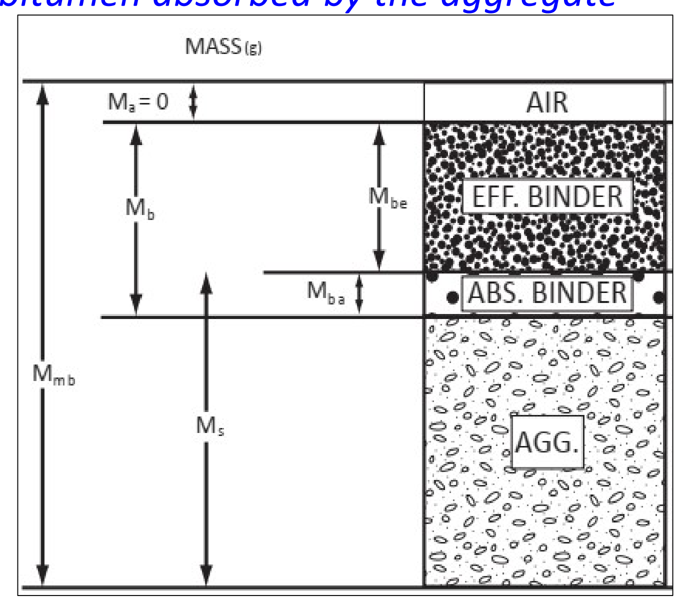
5.1.1 Maximum specific gravity is used

3) in calculating the amount of bitumen absorbed by the aggregate

- ❑ The portion of asphalt ***absorbed*** into the aggregate particles.
- ❑ Expressed as
  - ➢ *A percentage of the total aggregate mass*

➢ $P_{ba} = 100 \times \frac{M_{ba}}{M_s}$

➢ $P_{ba} = 100 \times \frac{(G_{se} - G_{sb})}{(G_{se} \times G_{sb})} \times G_b$



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5.1.1 Maximum specific gravity is used

4) to provide target values for the compaction of paving mixtures

Acceptance of Delivered and Laid Asphalt

Compaction achieved

- The compaction achieved (degree of compaction) after completion of rolling should always be within the pre-determined tolerance range.
- The degree of compaction is requested as
  1. *Percentage of Theoretical Maximum Density (or "percent Rice").*
  2. *Percentage of a laboratory-determined density.*
     - The laboratory density is usually a density obtained during mix design.
     - the ratio of bulk density obtained on site over the bulk density obtained in the laboratory for the target mix, expressed in percentage.
  3. *Percentage of a control strip density.*
     - A control strip is a short pavement section that is compacted to the desired value under close scrutiny then used as the compaction standard for a particular job.

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$$\%\ Compaction = \frac{G_{mb}\ of\ Extracted\ core}{G_{mm}\ at\ OBC\ from\ JMF}$$

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Specific Gravity for Asphalt Mixture

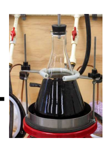
Theoretical Maximum Specific Gravity Gmm

Three specimens prepared at specified binder content

No.1 

No.2 

No.3 



Gmm Specimen No.1

Gmm Specimen No.2

Gmm Specimen No.3

$$Gmm_{mix} = \frac{(GmmS_1 + Gmm_{S2} + Gmm_{S3})}{3}$$

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5.1.1 Maximum specific gravity is used

5) Backcalculation of Gmm at other binder contents

- Since G_{se} is a constant then it can be used to **backcalculate G_{mm} at any asphalt binder content.**

$$G_{mm\,@Pb} = \frac{100}{\frac{P_s}{G_{se}} + \frac{P_b}{G_b}}$$

- P_s = percentage of aggregate by total mix weight
- P_b = percentage of binder by total mix weight
  - $P_s + P_b = 100$
- G_{se} = effective specific gravity of aggregate
- G_b = specific gravity of binder

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Step C : Preparation of Marshall Specimen

C-7: Calculate the G_{mm} at the other trial binder contents (



Measured Gmm @ Estimated (O.B.C) (Step C-6)

Find G_{se} for the aggregates

Back-calculate G_{mm} at the other trial binder contents

@ O.B.C - 0.5% | @ O.B.C -1.0% | @ O.B.C + 0.5% | @ O.B.C +1.0%

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