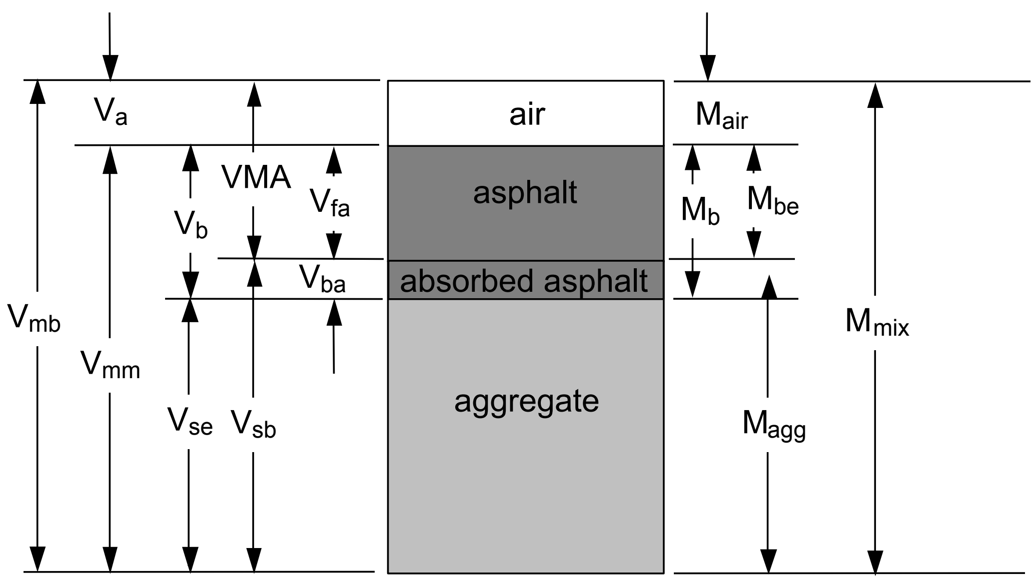
VI: Asphalt Mixture Volumetrics

A factor that must be taken into account when considering asphalt mixture behavior is the *volumetric proportions* of asphalt binder and aggregate components, or more simply, *asphalt mixture volumetrics*. The volumetric properties of a compacted paving mixture [air voids (V_a), voids in the mineral aggregate (VMA), voids filled with asphalt (VFA), and effective asphalt content (P_{be})] provide some indication of the mixture's probable pavement service performance. It is necessary to understand the definitions and analytical procedures described in this chapter to be able to make informed decisions concerning the selection of the design asphalt mixture.

This chapter describes volumetric analysis of HMA, which plays a significant role in most mixture design procedures, including the Superpave system. This chapter reviews the component relationships (mass and volume, aggregate and asphalt), presents the calculations for conducting a volumetric analysis, and describes the Superpave volumetric requirements. The information here applies to both paving mixtures that have been compacted in the laboratory, and to undisturbed samples that have been cut from a pavement in the field.

COMPONENT DIAGRAM

A tool that can assist in analyzing the properties of HMA is the component diagram -- a diagram that illustrates the individual components that make up the HMA: asphalt, aggregate and air. The simplified layout of the component diagram helps visualize the volumetric and mass relationships that are used in the analysis of HMA.



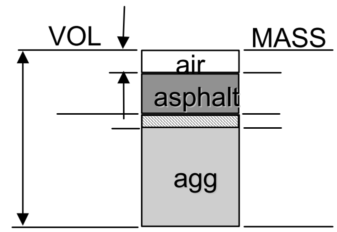
VMA = Volume of voids in mineral aggregate
V_{mb} = Bulk volume of compacted mix
V_{mm} = Voidless volume of paving mix
V_{fa} = Volume of voids filled with asphalt
V_a = Volume of air voids
V_b = Volume of asphalt binder
V_{ba} = Volume of absorbed asphalt binder
V_{sb} = Volume of mineral aggregate (by bulk specific gravity)
V_{se} = Volume of mineral aggregate (by effective specific gravity)

M = Total mass of asphalt mixture
M_b = Mass of asphalt binder
M_{be} = Mass of effective asphalt binder
M_{agg} = Mass of aggregate
M_{air} = Mass of air = 0

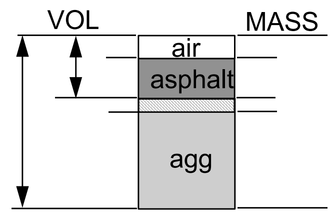
DEFINITIONS

Volumetric Properties of Asphalt Mixtures

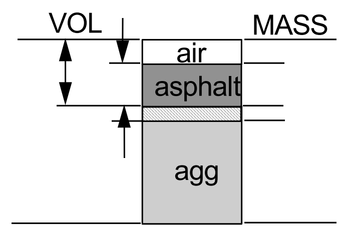
Air Voids, V_a - the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as percent of the total volume of the compacted paving mixture.



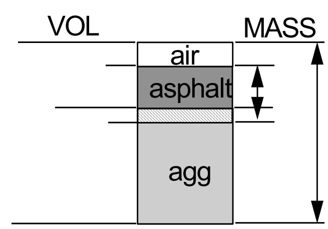
Voids in the Mineral Aggregate, VMA - the volume of intergranular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume of the compacted paving mixture.



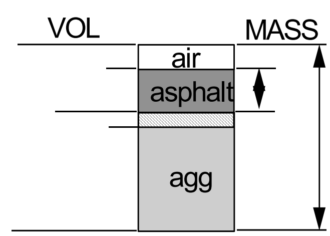
Voids Filled with Asphalt, VFA - the percentage portion of the volume of intergranular void space between the aggregate particles that is occupied by the effective asphalt. It is expressed as the ratio of (VMA - V_a) to VMA.



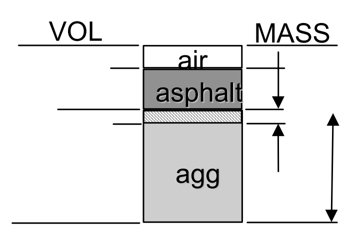
Asphalt Content, P_b - the total asphalt content of a paving mixture



Effective Asphalt Content, P_{be} - the total asphalt content of a paving mixture minus the portion of asphalt absorbed into the aggregate particles.



Absorbed Asphalt Content, P_{ba} - the portion of asphalt absorbed into the aggregate particles.



Specific Gravity

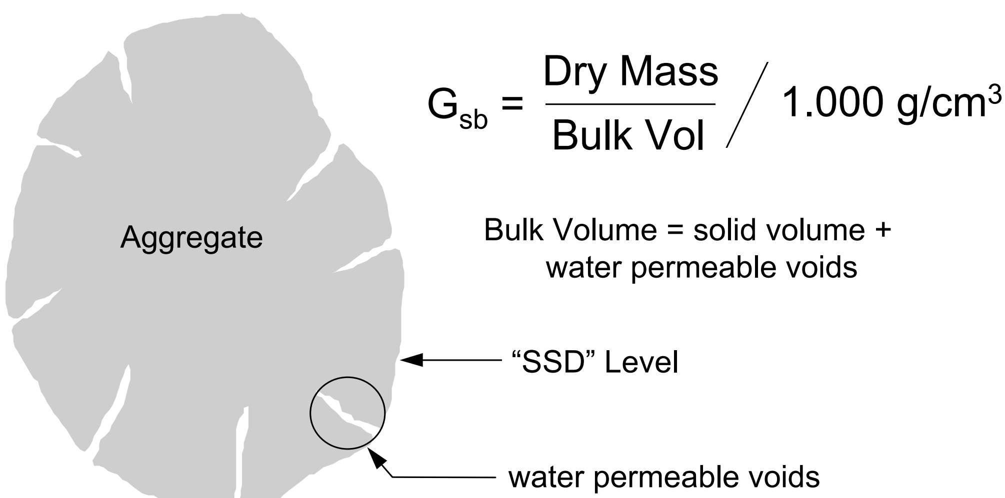
Specific gravity is "the ratio of the mass of a unit volume of a material to the mass of the same volume of water at stated temperatures." The mass of an object divided by its volume is its density, so another way to describe specific gravity is the density of an object divided by the density of water. Conveniently, at 25°C the density of water is 1.000 g/cm^3. Since the density of water is 1.000 at 25°C, the specific gravity of any object at 25°C is its weight divided by its volume. By knowing the specific gravity of an object, the volume can be calculated after measuring its mass, or the mass can be calculated after measuring its volume. Although the units for specific gravity and density are not the same, the terms are often used interchangeably. In fact, when using the metric units of g/cm^3, the values of density and specific gravity are numerically identical.

In the analysis of HMA, the specific gravities of the specific components of the HMA, as well as the specific gravities of the mixture, are used as "bridges" to go between the mass side of the component diagram and the volume side of the component diagram. Specific gravity is abbreviated using the letter G.

AGGREGATE SPECIFIC GRAVITIES

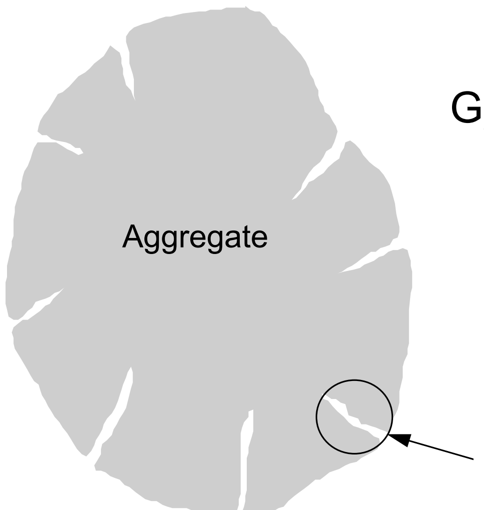
Mineral aggregate is porous and can absorb water and asphalt to a variable degree. Furthermore, the ratio of water to asphalt absorption varies with each aggregate. The three methods of measuring aggregate specific gravity take these variations into consideration. These methods are bulk, apparent, and effective specific gravities:

Bulk Specific Gravity, G_{sb} - the ratio of the mass in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) 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. In other words, the aggregate bulk specific gravity <u>includes</u> the volume of the water permeable voids in the aggregate (often termed the ""saturated surface dry" or SSD volume of the aggregate.



$$G_{sb} = \frac{\text{Dry Mass}}{\text{Bulk Vol}} \Big/ 1.000\ \text{g/cm}^3$$

Apparent Specific Gravity, G_{sa} - the ratio of the mass in air of a unit volume of an impermeable material 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. In other words, the aggregate apparent specific gravity <u>does not include</u> the volume of the water permeable voids in the aggregate

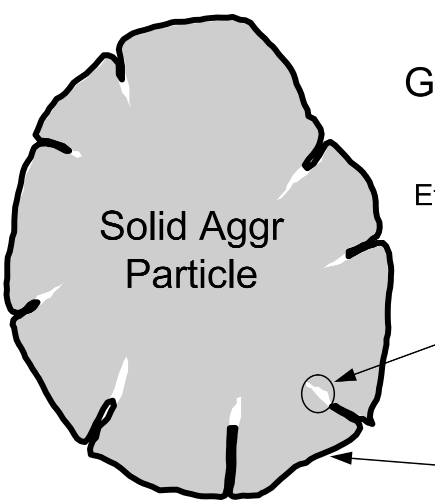


$$G_{sa} = \frac{\text{Dry Mass}}{\text{App Vol}} \Big/ 1.000\ \text{g/cm}^3$$

Apparent Volume = volume of solid aggr particle

Apparent volume <u>does not</u> include volume of surface pores

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. In other words, the effective specific gravity includes the volume of the water permeable voids in the aggregate that cannot be reached by the asphalt.



$$G_{se} = \frac{\text{Dry Mass}}{\text{Eff Vol}} \Big/ 1.000\ \text{g/cm}^3$$

Effective Volume = volume of solid aggr particle + volume of water permeable pores not filled with asphalt

volume of water permeable pores not filled with asphalt

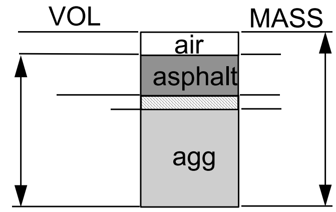
effective asphalt binder

When comparing specific gravities, the mass of the aggregate does not change; the volume does change. The bulk volume is greater than the effective volume, which is greater than the apparent volume. Since mass is divided by volume in calculating the specific gravity, G_{sa} will be larger than G_{se}, which will be larger than G_{sb}. Written symbolically, $V_{sb} > V_{se} > V_{sa}$, and $G_{sa} > G_{se} > G_{sb}$.

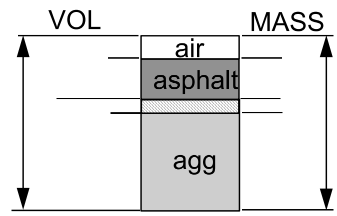
MIXTURE SPECIFIC GRAVITIES

Two measurements of the specific gravity of the HMA mixture are important in determining the volumetric properties of the HMA: the maximum theoretical specific gravity, G_{mm}, and bulk specific gravity, G_{mb}.

Maximum Theoretical Specific Gravity, G_{mm} - the ratio of the mass in air of a unit volume of the asphalt and aggregate in the mixture 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. In other words, the maximum theoretical specific gravity, G_{mm}, is the mass of the asphalt and aggregate mixture divided by the volume, not including the air voids.



Bulk Specific Gravity, G_{mb} - the ratio of the mass in air of a unit volume of the compacted asphalt and aggregate mixture 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. In other words, the bulk specific gravity, G_{mb}, is the mass of the asphalt and aggregate mixture divided by the volume, including the air voids.



Superpave mix design calculates VMA values for compacted paving mixtures in terms of aggregate bulk specific gravity, G_{sb}. Use of other aggregate specific gravities to compute VMA means that the VMA criteria no longer apply and the mixture may not meet the requirements of Superpave. The aggregate effective specific gravity, G_{se}, should be the basis for calculating the air voids in a compacted asphalt paving mixture.

Voids in the mineral aggregate (VMA) and air voids (V_a) are expressed as percent by volume of the paving mixture. Voids filled with asphalt (VFA) is the percentage of VMA filled by the effective asphalt. In Superpave, the total asphalt content and the effective asphalt content are expressed as a percentage of the total mass of the paving mixture.

Because air voids, VMA and VFA are volume quantities and therefore cannot be easily, a paving mixture must first be designed or analyzed in terms of volumes calculated from mass measurements. For mix production purposes, these volume quantities are later changed over to mass quantities to provide a job-mix formula that can be controlled at the plant.

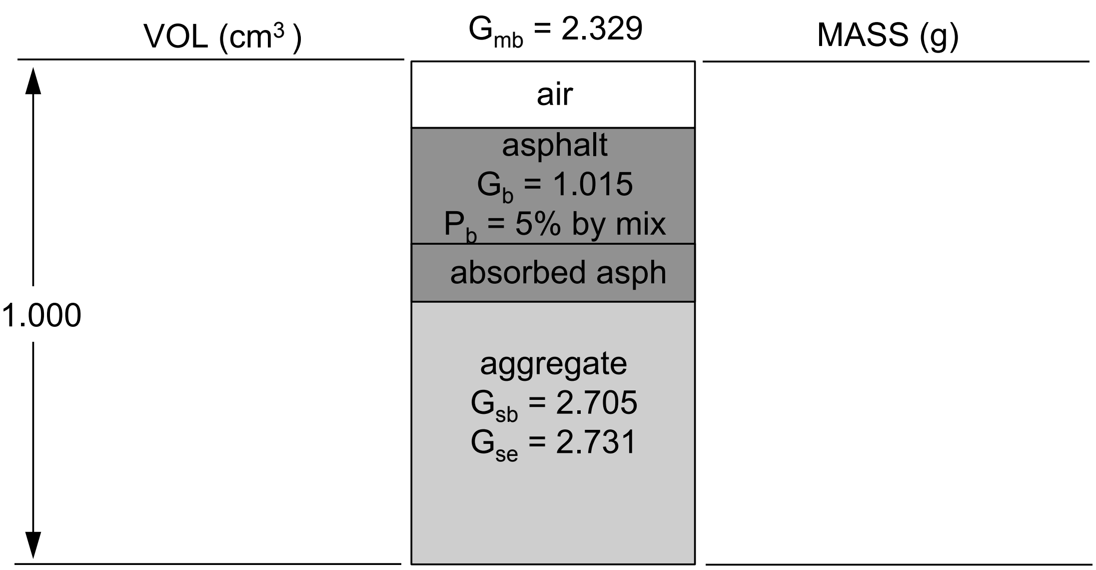
ANALYZING A COMPACTED PAVING MIXTURE

Two methods can be used to analyze the volumetric properties of compacted asphalt mixture. The first involves using the component diagram and various specific gravity measurements to calculate the relative masses and volumes of the mixture components, and then in turn calculating the volumetric properties. The second method uses the same specific gravity measurements with mathematical formulas to directly determine the mixture properties.

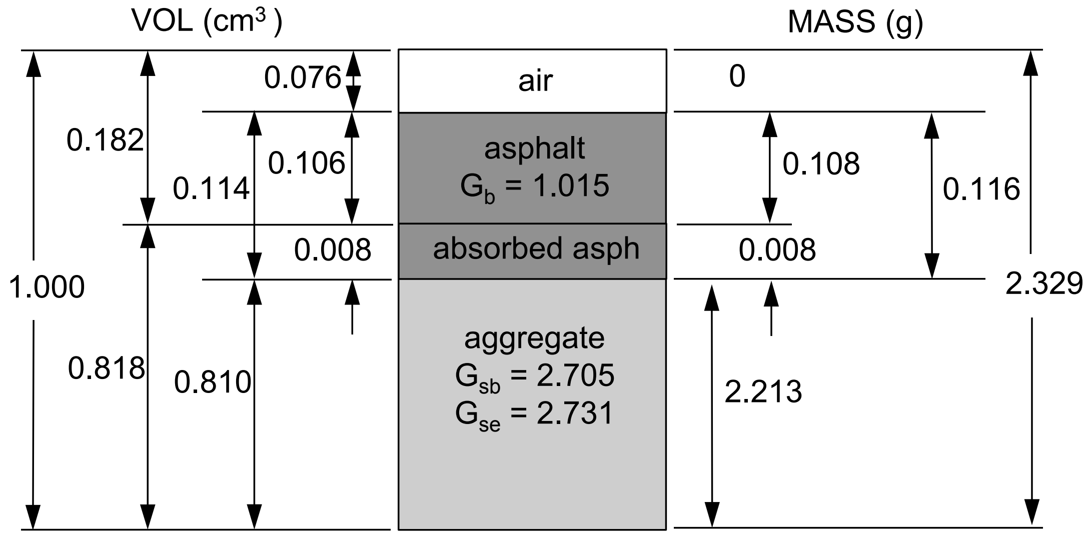
The first method is often used to illustrate the concepts behind the volumetric analysis of asphalt mixtures, and is therefore included in the presentation materials in this course. The second method, because the mathematical formulas can easily be placed into spreadsheet calculations, is more often used in laboratory mix design and analysis. These formulas are included in the text for information purposes, but are not detailed in the course presentation.

Component Diagram Method

This component diagram shows five properties (four specific gravities and the asphalt content) of a compacted specimen of HMA that have been measured at 25°C. Using only these few values, all of the volumetric properties and mass quantities of the HMA can be determined, as demonstrated in the course presentation.



These are the volumetric properties and mass quantities of this compacted specimen of HMA:



Air Voids = 7.6%
VMA = 18.2 %
VFA = 58.2 %

Effective Asphalt Content = 4.6%
Absorbed Asphalt Content = 0.4%
Max Theo Sp Grav = 2.521

Mathematical Equations Method

The measurements and calculations needed for a voids analysis are:

(a) Measure the bulk specific gravities of the coarse aggregate (AASHTO T 85 or ASTM C 127) and of the fine aggregate (AASHTO T 84 or ASTM C 128).
(b) Measure the specific gravity of the asphalt cement (AASHTO T 228 or ASTM D 70) and of the mineral filler (AASHTO T 100 or ASTM D 854).
(c) Calculate the bulk specific gravity of the aggregate combination in the paving mixture.
(d) Measure the maximum specific gravity of the loose paving mixture (ASTM D 2041 or AASHTO T209).
(e) Measure the bulk specific gravity of the compacted paving mixture (ASTM D 1188/D 2726 or AASHTO T166).
(f) Calculate the effective specific gravity of the aggregate.
(g) Calculate the maximum specific gravity at other asphalt contents.
(h) Calculate the asphalt absorption of the aggregate.
(i) Calculate the effective asphalt content of the paving mixture.
(j) Calculate the percent voids in the mineral aggregate in the compacted paving mixture.
(k) Calculate the percent air voids in the compacted paving mixture.
(l) Calculate the percent voids filled with asphalt in the compacted paving mixture

Equations for these calculations are found below.

This table provides the basic data for a sample of paving mixture. These design data are used in the sample calculations used in the remainder of this chapter.

Basic Data for Sample of Paving Mixture

Mixture Components				
	Specific Gravity		Mix Composition	
Material		Bulk	Percent by Mass of Total Mix	Percent By Mass of Total Aggregate
Asphalt Cement	1.030(G_b)		5.3 (P_b)	5.6 (P_b)
Coarse Aggregate		2.716(G_1)	47.4(P_1)	50.0(P_1)
Fine Aggregate		2.689(G_2)	47.3(P_2)	50.0(P_2)
Mineral Filler	---		---	---

Paving Mixture

Bulk specific gravity of compacted paving mixture sample, G_{mb} = 2.442
Maximum specific gravity of paving mixture sample, G_{mm} = 2.535

Bulk Specific Gravity of Aggregate

When the total aggregate consists of separate fractions of coarse aggregate, fine aggregate, and mineral filler, all having different specific gravities, the bulk specific gravity for the total aggregate is calculated using:

$$G_{sb} = \frac{P_1 + P_2 + \dots + P_N}{\frac{P_1}{G_1} + \frac{P_1}{G_2} + \dots + \frac{P_N}{G_N}}$$

where G_{sb} = bulk specific gravity for the total aggregate
P_1, P_2, P_N = individual percentages by mass of aggregate
G_1, G_2, G_N = individual bulk specific gravities of aggregate

The bulk specific gravity of mineral filler is difficult to determine accurately. However, if the apparent specific gravity of the filler is substituted, the error is usually negligible.

Using the sample paving mixture data:

$$G_{sb} = \frac{50.0 + 50.0}{\frac{50.0}{2.716} + \frac{50.0}{2.689}} = \frac{100}{18.41 + 18.59} = 2.703$$

Effective Specific Gravity of Aggregate

When based on the maximum specific gravity of a paving mixture, G_{mm}, the effective specific gravity of the aggregate, G_{se}, includes all void spaces in the aggregate particles except those that absorb asphalt. G_{se} is determined using:

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

where G_{se} = effective specific gravity of aggregate
G_{mm} = maximum specific gravity (ASTM D 2041/AASHTO T 209) of paving mixture (no air voids)
P_{mm} = percent by mass of total loose mixture = 100
P_b = asphalt content at which ASTM D 2041/AASHTO T 209 test was performed, percent by total mass of mixture
G_b = specific gravity of asphalt

Using the sample paving mixture data:

$$G_{se} = \frac{100 - 5.3}{\frac{100}{2.535} - \frac{5.3}{1.030}} = \frac{94.7}{39.45 - 5.15} = 2.761$$

NOTE: The volume of asphalt binder absorbed by an aggregate is almost invariably less than the volume of water absorbed. Consequently, the value for the effective specific gravity of an aggregate should be between its bulk and apparent specific gravities. When the effective specific gravity falls outside these limits, its value must be assumed to be incorrect. The calculations, the maximum specific gravity of the total mix by ASTM D 2041/AASHTO T 209, and the composition of the mix in terms of aggregate and total asphalt content should then be rechecked to find the source of the error.

Maximum Specific Gravity of Mixtures with Different Asphalt Contents

In designing a paving mixture with a given aggregate, the maximum specific gravity, G_{mm}, at each asphalt content is needed to calculate the percentage of air voids for each asphalt content. While the maximum specific gravity can be determined for each asphalt content by ASTM D 2041/AASHTO T 209, the precision of the test is best when the mixture is close to the design asphalt content. Also, it is preferable to measure the maximum specific gravity in duplicate or triplicate.

After calculating the effective specific gravity of the aggregate from each measured maximum specific gravity and averaging the G_{se} results, the maximum specific gravity for any other asphalt content can be obtained using the equation shown below. The equation assumes the effective specific gravity of the aggregate is constant, and this is valid since asphalt absorption does not vary appreciably with changes in asphalt content.

$$G_{mm} = \frac{P_{mm}}{\frac{P_s}{G_{se}} + \frac{P_b}{G_b}}$$

where G_{mm} = maximum specific gravity of paving mixture (no air voids)
P_{mm} = percent by mass of total loose mixture = 100
P_s = aggregate content, percent by total mass of mixture
P_b = asphalt content, percent by total mass of mixture
G_{se} = effective specific gravity of aggregate
G_b = specific gravity of asphalt

Using the specific gravity data from the sample paving mixture data, the effective specific gravity, G_{se}, and an asphalt content, P_b, of 4.0 percent:

$$G_{mm} = \frac{100}{\frac{96.0}{2.761} + \frac{4.0}{1.030}} = \frac{100}{34.77 + 3.88} = 2.587$$

Asphalt Absorption

Absorption is expressed as a percentage by mass of aggregate rather than as a percentage by total mass of mixture. Asphalt absorption, P_{ba}, is determined using:

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

where P_{ba} = absorbed asphalt, percent by mass of aggregate
G_{se} = effective specific gravity of aggregate
G_{sb} = bulk specific gravity of aggregate
G_b = specific gravity of asphalt

Using the bulk and effective aggregate specific gravities determined earlier and the asphalt specific gravity from the sample paving mixture data:

$$P_{ba} = 100 \times \frac{2.761 - 2.703}{2.703 \times 2.761} \times 1.030 = 100 \times \frac{0.058}{7.463} \times 1.030 = 0.8$$

Effective Asphalt Content of a Paving Mixture

The effective asphalt content, P_{be}, of a paving mixture is the total asphalt content minus the quantity of asphalt lost by absorption into the aggregate particles. It is the portion of the total asphalt content that remains as a coating on the outside of the aggregate particles and it is the asphalt content which governs the performance of an asphalt paving mixture. The formula is:

$$P_{be} = P_b - \frac{P_{ba}}{100} \times P_s$$

where P_{be} = effective asphalt content, percent by total mass of mixture
P_b = asphalt content, percent by total mass of mixture
P_{ba} = absorbed asphalt, percent by mass of aggregate
P_s = aggregate content, percent by total mass of mixture

Using the sample paving mixture data:

$$P_{be} = 5.3 - \frac{0.8}{100} \times 94.7 = 4.5$$

Percent VMA in Compacted Paving Mixture

The voids in the mineral aggregate, VMA, are defined as the intergranular void space between the aggregate particles in a compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume. The VMA is calculated on the basis of the bulk specific gravity of the aggregate and is expressed as a percentage of the bulk volume of the compacted paving mixture. Therefore, the VMA can be calculated by subtracting the volume of the aggregate determined by its bulk specific gravity from the bulk volume of the compacted paving mixture. The calculation is illustrated for each type of mixture percentage content.

If the mix composition is determined as percent by mass of total mixture:

$$VMA = 100 - \frac{G_{mb} \times P_s}{G_{sb}}$$

where VMA = voids in mineral aggregate (percent of bulk volume)
G_{sb} = bulk specific gravity of total aggregate
G_{mb} = bulk specific gravity of compacted mixture (ASTM D 1188 or D 2726/AASHTO T 166)
P_s = aggregate content, percent by total mass of mixture

Using the sample paving mixture data:

$$VMA = 100 - \frac{2.442 \times 94.7}{2.703} = 100 - 85.6 = 14.4$$

Or, if the mix composition is determined as percent by mass of aggregate:

$$VMA = 100 - \frac{G_{mb}}{G_{sb}} \times \frac{100}{100 + P_b} \times 100$$

where P_b = asphalt content, percent by mass of aggregate.

Using the sample paving mixture data:

$$VMA = 100 - \frac{2.442}{2.703} \times \frac{100}{100 + 5.6} \times 100 = 100 - 85.6 = 14.4$$

Percent Air Voids in Compacted Mixture

The air voids, V_a, in the total compacted paving mixture consist of the small air spaces between the coated aggregate particles. The volume percentage of air voids in a compacted mixture can be determined using:

$$V_a = 100 \times \frac{G_{mm} - G_{mb}}{G_{mm}}$$

where V_a = air voids in compacted mixture, percent of total volume
G_{mm} = maximum specific gravity of paving mixture (as calculated earlier or as determined directly for a paving mixture by ASTM D 2041/AASHTO T 209)
G_{mb} = bulk specific gravity of compacted mixture

Using the sample paving mixture data:

$$V_a = 100 \times \frac{2.535 - 2.442}{2.535} = 3.7$$

Percent VFA in Compacted Mixture

The percentage of the voids in the mineral aggregate that are filled with asphalt, VFA, not including the absorbed asphalt, is determined using:

$$VFA = 100 \times \frac{VMA - V_a}{VMA}$$

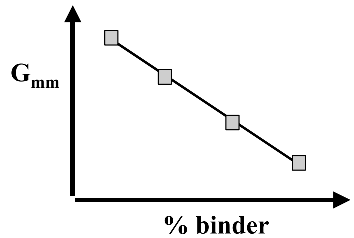
where, VFA = voids filled with asphalt, percent of VMA
VMA = voids in mineral aggregate, percent of bulk volume
V_a = air voids in compacted mixture, percent of total volume

Using the sample paving mixture data:

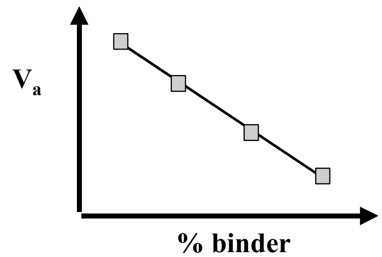
$$VFA = 100 \times \frac{14.4 - 3.7}{14.4} = 74.3$$

EFFECT OF CHANGING ASPHALT CONTENT ON VOLUMETRIC PROPERTIES

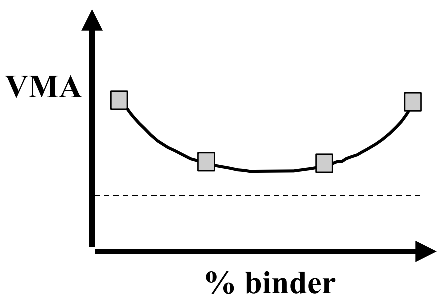
Maximum Theoretical Specific Gravity at Other Asphalt Contents



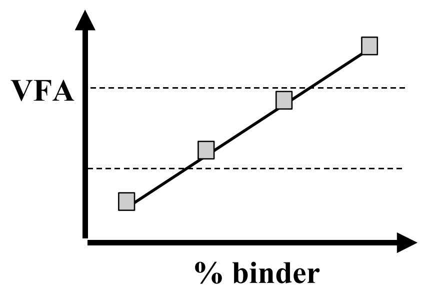
Air Void Content



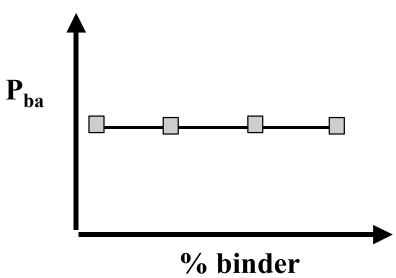
Voids in the Mineral Aggregate



Voids Filled With Asphalt



Absorbed Asphalt Content



Effective Asphalt Content