VOLUMETRIC PROPERTIES OF ASPHALT MIXTURES
WAQTC TM 13

Scope

This procedure covers the determination of volumetric properties of plant produced ~~Hot Mix Asphalt~~asphalt mixtures, i.e., air voids (V_a), voids in mineral aggregate (VMA), voids filled with asphalt binder (VFA), effective asphalt binder content (P_{be}) and Dust to Binder Ratio ($P_{\#200}/P_{be}$). The in-production volumetric properties are then compared to agency specifications.

Definition of Terms

- G_{mm} = theoretical maximum specific gravity (Gravity $_{mix\ max}$)
- G_{mb} = measured bulk specific gravity (Gravity $_{mix\ bulk}$)
- G_{sb} = oven-dry bulk specific gravity of aggregate (Gravity $_{stone\ bulk}$)
- G_{sa} = apparent specific gravity of aggregate (Gravity $_{stone\ apparent}$)
- G_{se} = effective specific gravity of aggregate (Gravity $_{stone\ effective}$)
- G_b = specific gravity of the binder (Gravity $_{binder}$)
- V_a = air Voids (Voids $_{air}$)
- VMA = Voids in Mineral Aggregate
- VFA = Voids Filled with Asphalt (binder)
- V_{ba} = absorbed binder volume (Voids $_{binder\ absorbed}$)
- V_{be} = effective binder volume (Voids $_{binder\ effective}$)
- P_b = percent binder content (Percent $_{binder}$)
- P_{ba} = percent absorbed binder (Percent $_{binder\ absorbed}$)
- P_{be} = percent effective binder content (Percent $_{binder\ effective}$)
- P_s = percent of aggregate (Percent $_{stone}$)
- DP = Dust proportion to effective binder ratio ($P_{\#200}/P_{be}$)

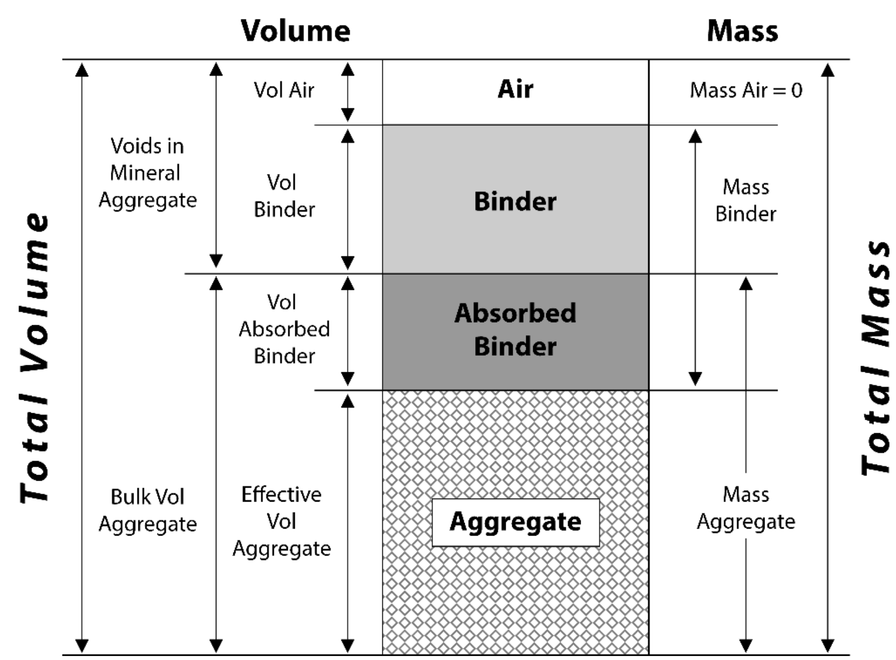
Background

Whether a mix design is developed through a Marshall, Hveem, or Superpave mix design process there are basic volumetric requirements of all. Volumetric properties are the properties of a defined material contained in a known volume. Asphalt mixture volumetric properties can include bulk specific gravity, theoretical maximum specific gravity, air voids, and voids in mineral aggregate.

Many agencies specify values of the volumetric properties to ensure optimum performance of the pavement. The asphalt mixture must be designed to meet these criteria. In production the asphalt mixture is evaluated to determine if the mix still meets the specifications and is consistent with the original mix design (JMF). The production asphalt mixture may vary from the mix design and may need to be modified to meet the specified volumetric criteria.

To compare the in-production volumetric properties to agency specifications and the JMF a sample of loose asphalt mixture mix is obtained in accordance with FOP for AASHTO R 97. The sample is then compacted in a gyratory compactor to simulate the in-place asphalt mixture pavement after it has been placed, compacted, and the volumetric properties of the compacted sample are determined.

Asphalt mixture phase diagram

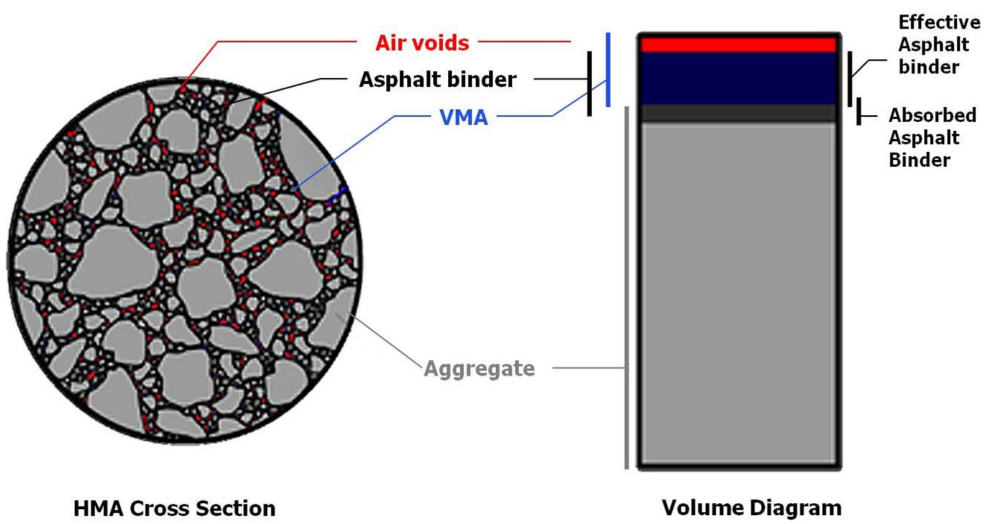


Each of the properties in the asphalt mixture phase diagram can be measured or calculated. For example: The mass of the aggregate is measured; the voids in mineral aggregate (VMA) is calculated; total asphalt binder can be measured but the amount available to act as a binder in the mix must be calculated because it is the quantity left after the aggregate has absorbed some of the asphalt binder.

The volumetric proportions of the asphalt binder and aggregate components of an asphalt mixture and their relationship to the other components are considered. The mass of the components and their specific gravities are used to determine the volumes of each of the components in the mix. The volumetric properties of a compacted asphalt mixture: air voids (V_a), voids in mineral aggregate (VMA), voids filled with asphalt binder (VFA), and effective asphalt binder content (P_{be}) provide some indication of the mixture's probable performance.

Volumetric Properties

Volumetric Relationship of Asphalt Mixture Constituents



Required Values

The specific gravities listed in Table 1 and the percent by mass of each of the components in the asphalt mixture are needed to determine the volumetric properties. Other values required are also listed. Some of these values are obtained from the JMF and some are measured from a plant produced asphalt mixture sample.

Table 1

Data	Test Method	Obtained
G_{sb} - combined aggregate bulk specific gravity	AASHTO T 84 / T 85 or agency approved test method	JMF or performed at the beginning of placement
G_b – measured specific gravity of the asphalt binder	AASHTO T 228	JMF or from the supplier
G_{mm} – measured maximum specific gravity of the loose mix	FOP for AASHTO T 209	Performed on the field test sample
G_{mb} – measured bulk specific gravity of the compacted paving mix	FOP for AASHTO T 166	Performed on the field compacted specimen
P_b – percent asphalt binder	FOP for AASHTO T 308	Performed on the field test sample
$P_{-\#200}$ – aggregate passing the #200 (75 µm) sieve	FOP for AASHTO T 30	Performed on the field test sample

Air Voids (V_a)

Air voids are the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture. Appropriate air voids contribute to the stability of the asphalt mixture and help the pavement withstand the combined action of environment and traffic loads. The designated percent air voids allows for thermal expansion of the asphalt binder and contributes a cushion for future compaction. Air voids are expressed as a percent of the bulk volume of the compacted mixture (G_{mb}) when compared to the maximum specific gravity (G_{mm}).

$$V_a = 100\left[\frac{(G_{mm} - G_{mb})}{G_{mm}}\right]$$

Where:

V_a = air voids in compacted mixture, percent of total volume (report to 0.1)
G_{mm} = maximum specific gravity of paving mixture (AASHTO T 209)
G_{mb} = bulk specific gravity of compacted mixture (AASHTO T 166)

Percent Aggregate (Stone) (P_s)

P_s is the percent aggregate (stone) content, expressed as a percentage of the total mass of the sample.

$$P_s = 100 - P_b$$

Where:

P_s = percent aggregate (stone) percent by total weight
P_b = asphalt binder content (AASHTO T 308)

Voids in the Mineral Aggregate (VMA)

VMA is the volume of intergranular void space between the aggregate particles of the compacted paving mixture that includes the air voids and the effective binder content, expressed as a percent of the total volume of the sample.

$$VMA = 100 - \left[\frac{(G_{mb} \times P_s)}{G_{sb}}\right]$$

Where:

VMA = voids in mineral aggregate, percent of bulk volume (report to 0.1)

G_{sb} = bulk specific gravity of combined aggregate (AASHTO T 85 / T 84 or agency approved method from Job Mix Formula)

G_{mb} = bulk specific gravity of compacted mixture (AASHTO T 166)

P_s = aggregate content, percent by total weight = 100 – P_b

P_b = asphalt binder content (AASHTO T 308) percent by total weight

Voids Filled with Asphalt (binder) (VFA)

VFA is the volume of space between the aggregate particles of the compacted paving mixture filled with asphalt binder, expressed as a percent of the total volume of the sample. The VFA increases as the asphalt binder content increases as it is the percent of voids that are filled with asphalt which doesn't include the absorbed asphalt.

$$VFA = 100\left[\frac{(VMA - V_a)}{VMA}\right]$$

Where:

VFA = voids filled with asphalt, percent of VMA (report to 1)
VMA = voids in mineral aggregate, percent of bulk volume
V_a = air voids in compacted mixture, percent of total volume.

Effective Specific Gravity of the Aggregate (Stone) (G_{se})

The G_{se} is used to quantify the asphalt binder absorbed into the aggregate particle. This is a calculated value based on the specific gravity of the mixture, G_{mm}, and the specific gravity of the asphalt binder, G_b This measurement includes the volume of the aggregate particle plus the void volume that becomes filled with water during the test soak period minus the volume of the voids that absorb asphalt binder. Effective specific gravity lies between apparent and bulk specific gravity.

G_{se} is formally defined as the ratio of the mass in air of a unit volume of a permeable material (excluding voids permeable to asphalt binder) 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.

$$G_{se} = \frac{P_s}{\left[\left(\frac{100}{G_{mm}}\right) - \left(\frac{P_b}{G_b}\right)\right]}$$

Where:

G_{se} = effective specific gravity of combined aggregate (report to 0.001)
P_s = aggregate content, percent by total weight = 100 – P_b
G_{mm} = maximum specific gravity of mix (AASHTO T 209)
P_b = asphalt binder content (AASHTO T 308) percent by total weight
G_b = specific gravity of asphalt binder (JMF or asphalt binder supplier)

Percent of Absorbed (asphalt) Binder (P_{ba})

P_{ba} is the total percent of the asphalt binder that is absorbed into the aggregate, expressed as a percentage of the mass of aggregate rather than as a percentage of the total mass of the mixture. This portion of the asphalt binder content does not contribute to the performance of the mix.

$$P_{ba} = 100\left[\frac{(G_{se} - G_{sb})}{(G_{sb} \times G_{se})}\right] G_b$$

Where:

P_{ba} = absorbed asphalt binder (report to 0.01) percent of aggregate

G_{se} = effective specific gravity of combined aggregate
G_{sb} = bulk specific gravity of combined aggregate (AASHTO T 85 / T 84 or agency approved method from Job Mix Formula)
G_b = specific gravity of asphalt binder (JMF or asphalt binder supplier)

Percent of Effective (asphalt) Binder (P_{be})

P_{be} is the total asphalt binder content of a paving mixture minus the portion of asphalt binder that is lost by absorption into the aggregate particles, expressed as a percentage of the mass of aggregate. It is the portion of the asphalt binder content that remains as a coating on the outside of the aggregate particles. This is the asphalt content that controls the performance of the mix.

$$P_{be} = P_b - \left[\frac{P_{ba}}{100} \times P_s\right]$$

Where:

P_{be} = effective asphalt binder content (report to 0.01), percent by total weight

P_s = aggregate content, percent by total weight = 100 – P_b

P_b = asphalt binder content (AASHTO T 308) percent by total weight

P_{ba} = absorbed asphalt binder

Dust Proportion – DP (Dust to Effective (asphalt) Binder Ratio)

The DP is the percent passing the No. 200 sieve of the gradation divided by the percent of effective asphalt binder. Excessive dust reduces asphalt binder film thickness on the aggregate which reduces the durability. Insufficient dust may allow excessive asphalt binder film thickness, which may result in a tender, unstable mix.

$$DP = \frac{P_{-\#200}}{P_{be}}$$

Where:

DP = Dust Proportion, (dust-to-binder ratio) (report to 0.01)

$P_{-\#200}$ = aggregate passing the -#200 (75 µm) sieve, percent by mass of aggregate (AASHTO T 30)

P_{be} = effective asphalt binder content, percent by total weight

Mix Design and Production Values

Job Mix Formula

Table 2 includes example data required from the JMF. Some of these values are used in the example calculations.

Note: Some of the targets may change after the asphalt mixture is in production based on field test data.

Table 2

JMF Data	
Asphalt binder grade	PG 64-28
N_{values}	N_{ini} = 7 $\mathbf{N_{des}}$ **= 75** N_{max} = 115
G_{sb} (combined specific gravity of the aggregate)	2.678
Target P_b	4.75%
Initial sample mass for gyratory specimens	4840 grams
Mixing temperature range	306 – 312 °F
Laboratory compaction temperature range	286 – 294 °F
G_b (specific gravity of the asphalt binder)	1.020
Target gradation	
Sieve Size mm (in.)	**Percent Passing**
19.0 (3/4)	100
12.5 (1/2)	85
9.5 (3/8)	80
4.75 (No. 4)	50
2.36 (No. 8)	30
01.18 (No. 16)	25
0.600 -(No. 30)	15
0.300 (No. 50)	10
0.150 (No. 100)	7
75 µm (No. 200)	5.0

Sample Test Result

Tables 3 and 4 include data from test results performed on a field sample of asphalt mixture used in the example calculations.

Table 3

Field Data		
	Test method	**Example values**
P_b	FOP for AASHTO T 308	4.60%
G_{mb}	FOP for AASHTO T 166	2.415
G_{mm}	FOP for AASHTO T 209	2.516

Table 4

Sieve Analysis FOP for AASHTO T 30	
Sieve Size mm (in.)	**Percent Passing**
19.0 (3/4)	100
12.5 (1/2)	86
9.5 (3/8)	77
4.75 (No. 4)	51
2.36 (No. 8)	34
01.18 (No. 16)	23
0.600 (No. 30)	16
0.300 (No. 50)	12
0.150 (No. 100)	8
75 µm (No. 200)	4.9

Sample Calculations

Air Voids (V_a)

$$V_a = 100\left[\frac{(G_{mm} - G_{mb})}{G_{mm}}\right]$$

$$V_a = 100\left[\frac{(2.516 - 2.415)}{2.516}\right] = 4.01431\%\ report\ 4.0\%$$

Given:

G_{mm} = 2.516

G_{mb} = 2.415

Percent Aggregate (Stone) (P_s)

$$P_s = 100 - P_b$$

$$P_s = 100.0 - 4.60\% = 95.40\%$$

Given:

P_b = 4.60%

Voids in the Mineral Aggregate (VMA)

$$VMA = 100 - \left[\frac{(G_{mb} \times P_s)}{G_{sb}}\right]$$

$$VMA = 100.0 - \left[\frac{2.415 \times 95.40\%)}{2.678}\right] = 13.96\%\ report\ 14.0\%$$

Given:

G_{sb} =2.678

Voids Filled with Asphalt (binder) (VFA)

$$VFA = 100\left[\frac{(VMA - V_a)}{VMA}\right]$$

$$VFA = 100\left[\frac{(14.0\% - 4.0\%)}{14.0\%}\right] = 71.4\%\ report\ 71\%$$

Effective Specific Gravity of the Aggregate (Stone) (G_{se})

$$G_{se} = \frac{P_s}{\left[\left(\frac{100}{G_{mm}}\right) - \left(\frac{P_b}{G_b}\right)\right]}$$

$$G_{se} = \frac{(100 - 4.60\%)}{\left[\left(\frac{100}{2.516}\right) - \left(\frac{4.60\%}{1.020}\right)\right]} =$$

$$G_{se} = \frac{95.40\%}{39.74563 - 4.50980} = 2.70747\ report\ 2.707$$

Given:

G_b = 1.020

Percent of Absorbed (asphalt) Binder (P_{ba})

$$P_{ba} = 100\left[\frac{(G_{se} - G_{sb})}{(G_{sb} \times G_{se})}\right] G_b$$

$$P_{ba} = 100\left[\frac{(2.707 - 2.678)}{(2.678 \times 2.707)}\right] 1.020 =$$

$$P_{ba} = 100\left[\frac{0.0290}{7.24935}\right] 1.020 = 0.40804\%\ report\ 0.41\%$$

Percent of Effective (asphalt) Binder (P_{be})

$$P_{be} = P_b - \left[\frac{P_{ba}}{100} \times P_s\right]$$

$$P_{be} = 4.60 - \left[\frac{0.41\%}{100} \times (100 - 4.60\%)\right] = 4.20886\%\ report\ 4.21\%$$

Dust Proportion – DP (Dust to Effective (asphalt) Binder Ratio)

$$DP = \frac{P_{-\#200}}{P_{be}}$$

$$DP = \frac{4.9\%}{4.21\%} = 1.16390\ report\ 1.16$$

Given:

$P_{-\#200}$ = 4.9%

Report

- On forms approved by the agency
- Sample ID
- Air Voids, V_a to the nearest 0.1 percent
- Voids in the Mineral Aggregate, VMA to the nearest 0.1 percent
- Voids Filled with Asphalt, VFA to the nearest whole value
- Effective Specific Gravity of Aggregate (stone), G_{se} to the nearest 0.001
- Percent of Absorbed (asphalt) Binder, P_{ba} to the nearest 0.01
- Percent Effective (asphalt) Binder, P_{be} to the nearest 0.01
- Dust Proportion, DP to the nearest 0.01

Appendix - Formulas

Air Voids (V_a)

$$V_a = 100\left[\frac{(G_{mm} - G_{mb})}{G_{mm}}\right]$$

Where:

V_a = air voids in compacted mixture, percent of total volume (report to 0.1)
G_{mm} = maximum specific gravity of paving mixture (AASHTO T 209)
G_{mb} = bulk specific gravity of compacted mixture (AASHTO T 166)

Percent Aggregate (Stone) (P_s)

$$P_s = 100 - P_b$$

Where:
P_s = percent aggregate (stone) percent by total weight
P_b = asphalt binder content (AASHTO T 308)

Voids in the Mineral Aggregate (VMA)

$$VMA = 100 - \left[\frac{(G_{mb} \times P_s)}{G_{sb}}\right]$$

Where:

VMA = voids in mineral aggregate, percent of bulk volume (report to 0.1**)**

G_{sb} = bulk specific gravity of combined aggregate (AASHTO T 85 / T 84 or agency approved method from Job Mix Formula)

G_{mb} = bulk specific gravity of compacted mixture (AASHTO T 166)

P_s = aggregate content, percent by total weight = 100 – P_b

P_b = asphalt binder content (AASHTO T 308) percent by total weight

Voids Filled with Asphalt (binder) (VFA)

$$VFA = 100\left[\frac{(VMA - V_a)}{VMA}\right]$$

Where:
VFA = voids filled with asphalt, percent of VMA (report to 1)
VMA = voids in mineral aggregate, percent of bulk volume
V_a = air voids in compacted mixture, percent of total volume.

Effective Specific Gravity of the Aggregate (Stone) (G_{se})

$$G_{se} = \frac{P_s}{\left[\left(\frac{100}{G_{mm}}\right) - \left(\frac{P_b}{G_b}\right)\right]}$$

Where:

G_{se} = effective specific gravity of combined aggregate (report to 0.001)
P_s = aggregate content, percent by total weight = 100 – P_b
G_{mm} = maximum specific gravity of mix (AASHTO T 209)
P_b = asphalt binder content (AASHTO T 308) percent by total weight
G_b = specific gravity of asphalt binder (JMF or asphalt binder supplier)

Percent of Absorbed (asphalt) Binder (P_{ba})

$$P_{ba} = 100\left[\frac{(G_{se} - G_{sb})}{(G_{sb} \times G_{se})}\right]G_b$$

Where:

P_{ba} = absorbed asphalt binder (report to 0.01) percent of aggregate
G_{se} = effective specific gravity of combined aggregate
G_{sb} = bulk specific gravity of combined aggregate (AASHTO T 85 from Job Mix Formula)
G_b = specific gravity of asphalt binder (JMF or asphalt binder supplier)

Percent of Effective (asphalt) Binder (P_{be})

$$P_{be} = P_b - \left[\frac{P_{ba}}{100} \times P_s\right]$$

Where:

P_{be} = effective asphalt binder content (report to 0.01), percent by total weight

P_s = aggregate content, percent by total weight = 100 – P_b

P_b = asphalt binder content (AASHTO T 308) percent by total weight

P_{ba} = absorbed asphalt binder

Dust Proportion – DP (Dust to Effective (asphalt) Binder Ratio)

$$DP = \frac{P_{-\#200}}{P_{be}}$$

Where:

DP = Dust Proportion, (dust-to-binder ratio) (report to 0.01)

$P_{-\#200}$ = aggregate passing the -#200 (75 µm) sieve, percent by mass of aggregate (AASHTO T 30)

P_{be} = effective asphalt binder content, percent by total weight