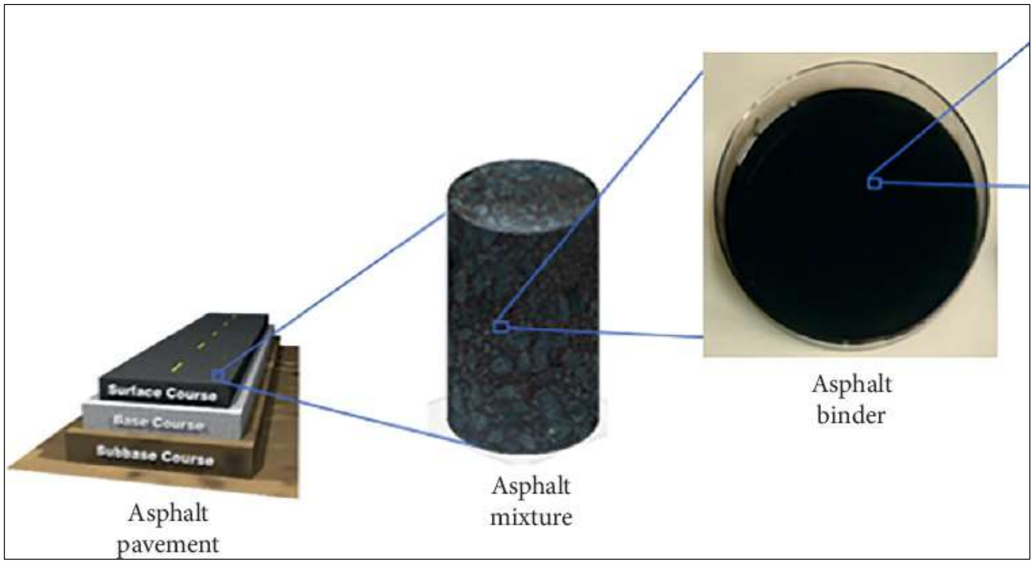
Pavement Materials & Design

Asphalt Mixtures

Volumetric Analysis

HMA Mix Design

Asphalt Mixtures Types



Qu, X., D. Wang, L. Wang, Y. Huang, Yue Hou and M. Oeser. "TheState-ofthe-ArtReviewonMolecularDynamics Simulationof Asphalt Binder." (2018).

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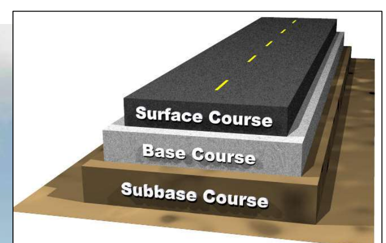

Image source: http://gilsoniteco.com/2018/02/22/gilsonite-binder-grade/

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Hot Mix | Parklea Sand and Soil (parkleasandsoil.com.au)

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

Asphalt Cement/Binder

About 4% to 6% of total mix by weight

About 10% to 14% of total mix by volume

Aggregates

About 94% - 96% of total mix by weight

About 75%-85% of total mix by volume

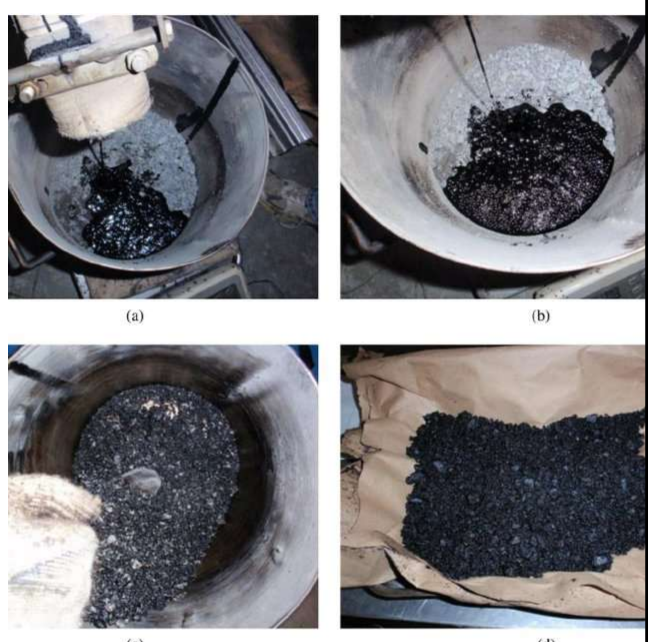

Image source: https://www.floridaridesonus.org/learning-center/asphalt-101/

HMA Mix Design

Asphalt Mixtures Types

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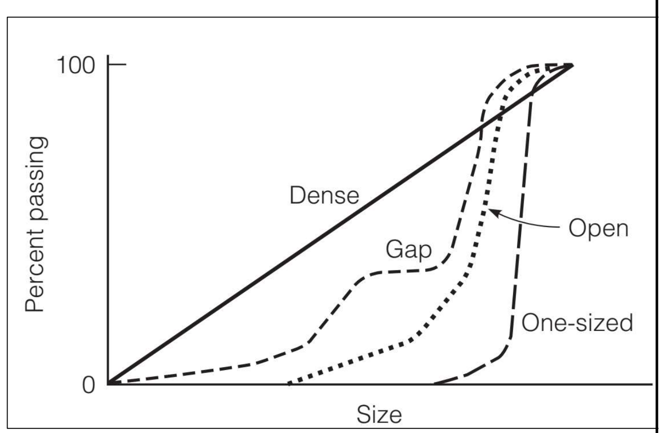
Classification of Asphalt Mixtures

- Asphalt mixtures may be produced from a wide range of aggregate combinations, each having its own particular characteristics suited to specific design and construction uses.
- Popular asphalt Mixtures
  - *Dense-graded asphalt Mixtures*
  - *Open-graded asphalt Mixtures*
  - *Gap-graded or Stone Matrix Asphalt (SMA)*



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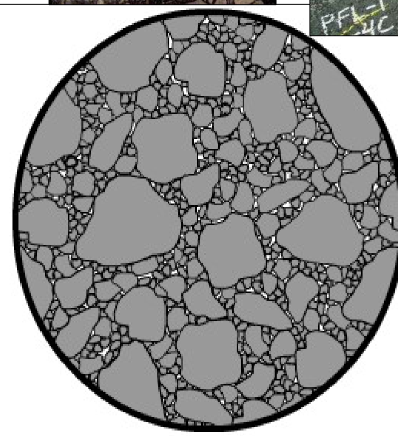
Dense-graded asphalt Mixtures

- A dense-graded asphalt mix has a well-distributed aggregate gradation throughout the entire range of sieves used.
- It is the most commonly specified type of mix and can be used in the base, intermediate layers and surface of a pavement structure.
- Superpave, Marshall and Hveem are methods of designing dense-graded Mixtures



Dense graded HMA contains all sizes of aggregate particles. There are enough fine particles to effectivly separate many of the coarse particles. Therefore, stress transmission through the HMA structure relies on both the coarse and fine particles. VMA is generally between 11 and 17%, air voids are generally near 4%, and asphalt binder content can range between 4.5 to 6%.

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HMA Mix Design

Asphalt Mixtures Volumetric

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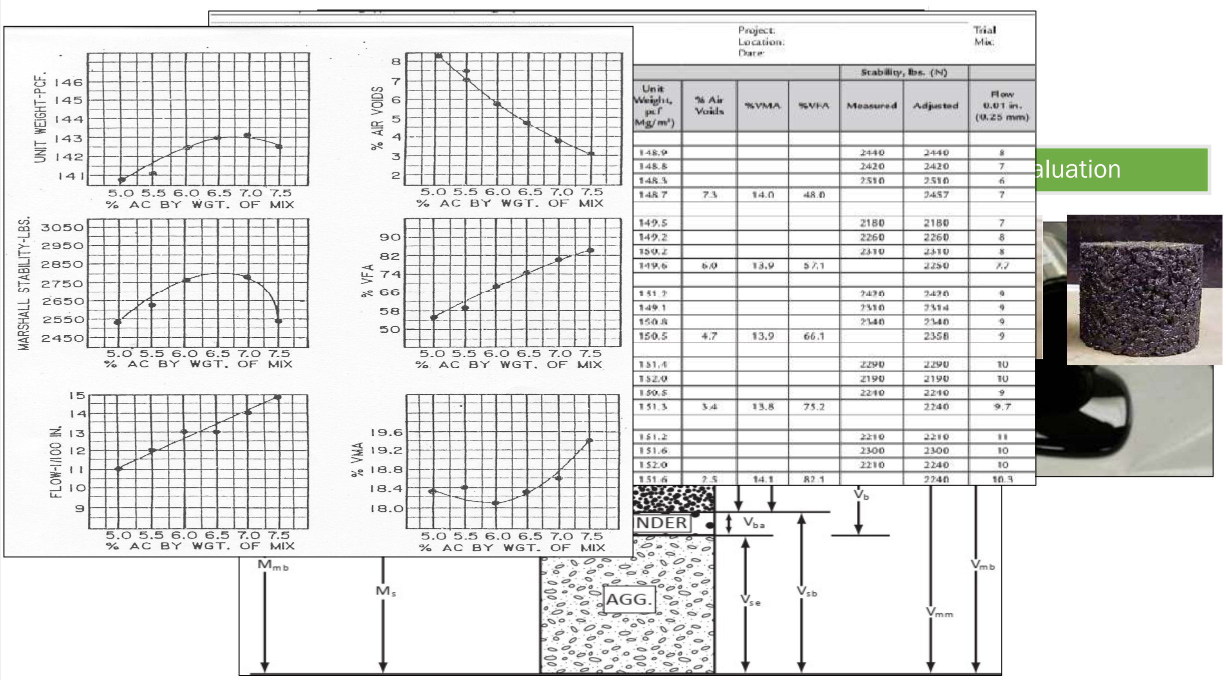
Introduction

- 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

A loose asphalt mixture typically refers to a mix of asphalt and aggregate materials that has not undergone the compaction process.

Laboratory

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

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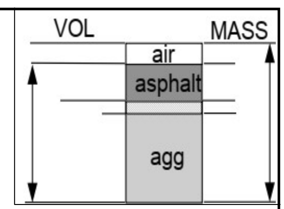
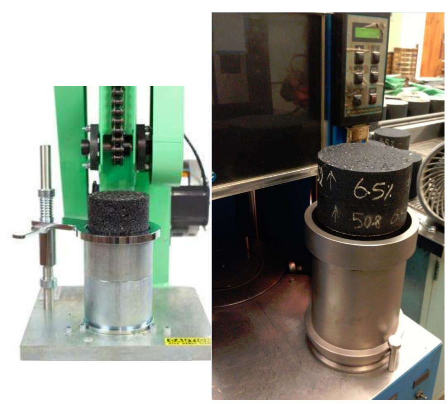
Mixture phases

Compacted Mixture



Field compacted

A compacted asphalt mixture typically refers to a mix of asphalt and aggregate materials that has undergone the compaction process.



Laboratory compacted

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

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Loose Specimen

Compacted Specimen

Image source: http://asphaltmagazine.com/fix-your-mix/

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

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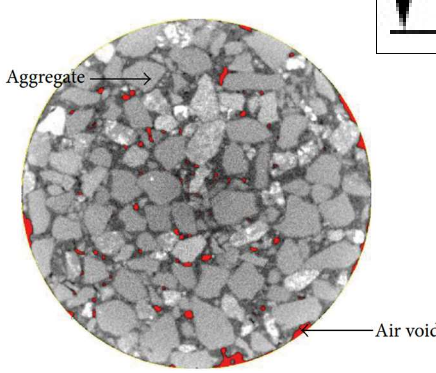
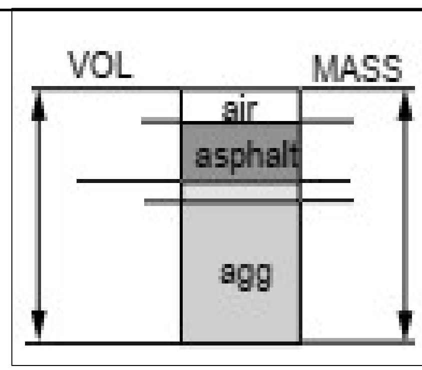
Mixture phases

Compacted specimen





https://downloads.hindawi.com/journals/amse/2014/507082.pdf

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Asphalt Mixture

The volumetric relationship

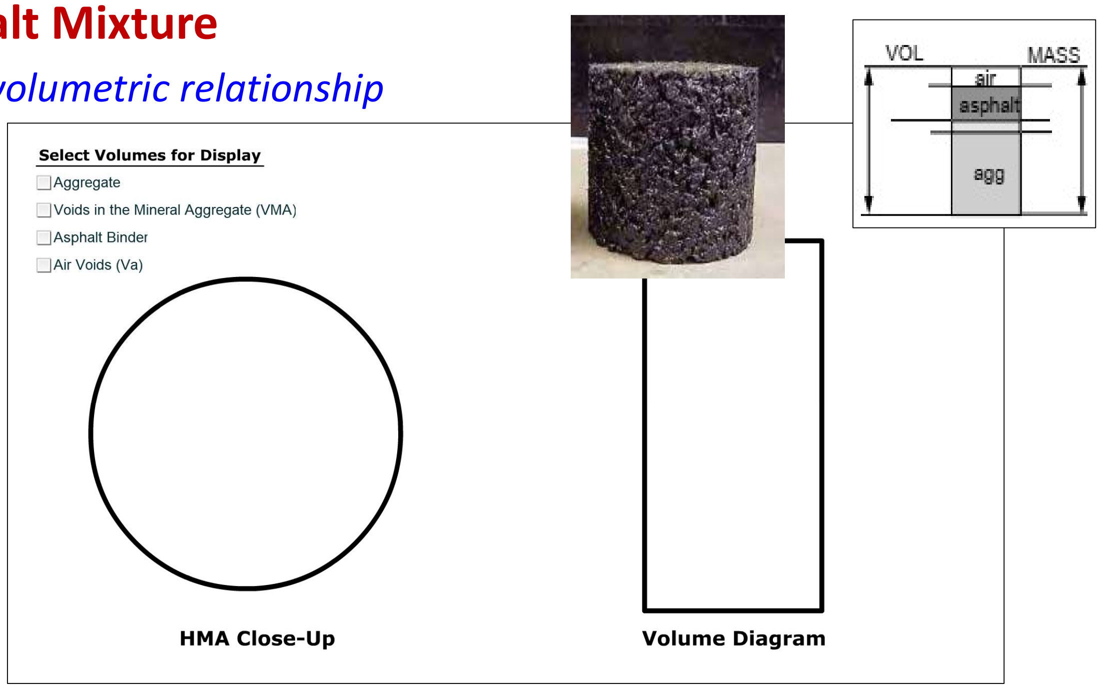

*Image source:*https://pavementinteractive.org/reference-desk/design/mix-design/hma-weight-volume-terms-and-relationships/

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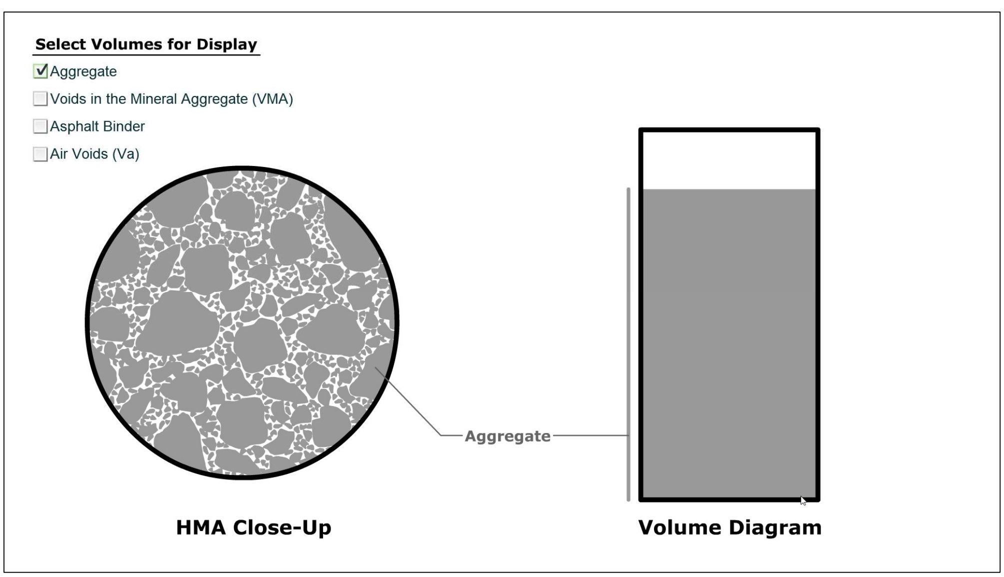
Asphalt Mixture

The volumetric relationship



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Asphalt Mixture

The volumetric relationship

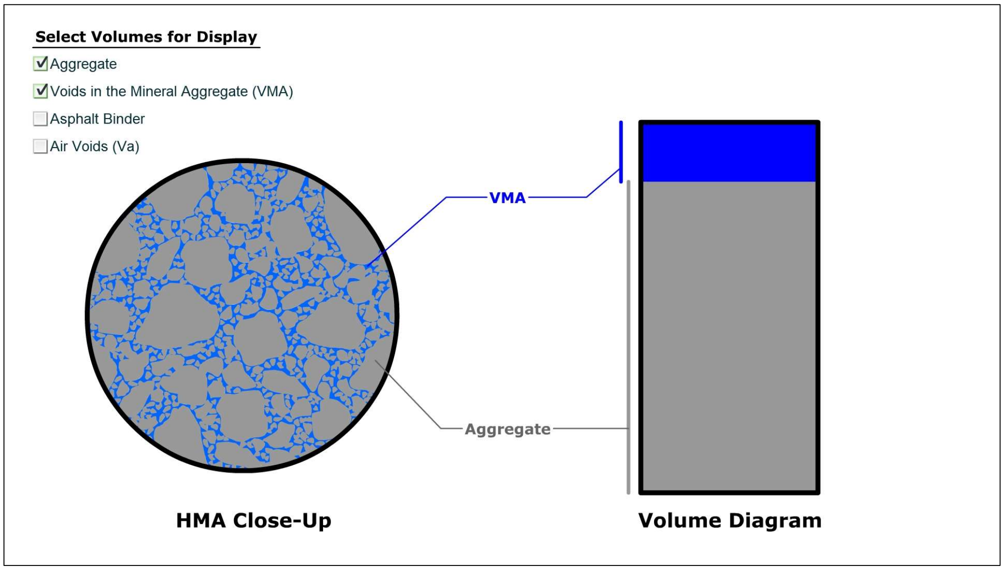

Image source:https://pavementinteractive.org/reference-desk/design/mix-design/hma-weight-volume-terms-and-relationships/

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Asphalt Mixture

The volumetric relationship HMA

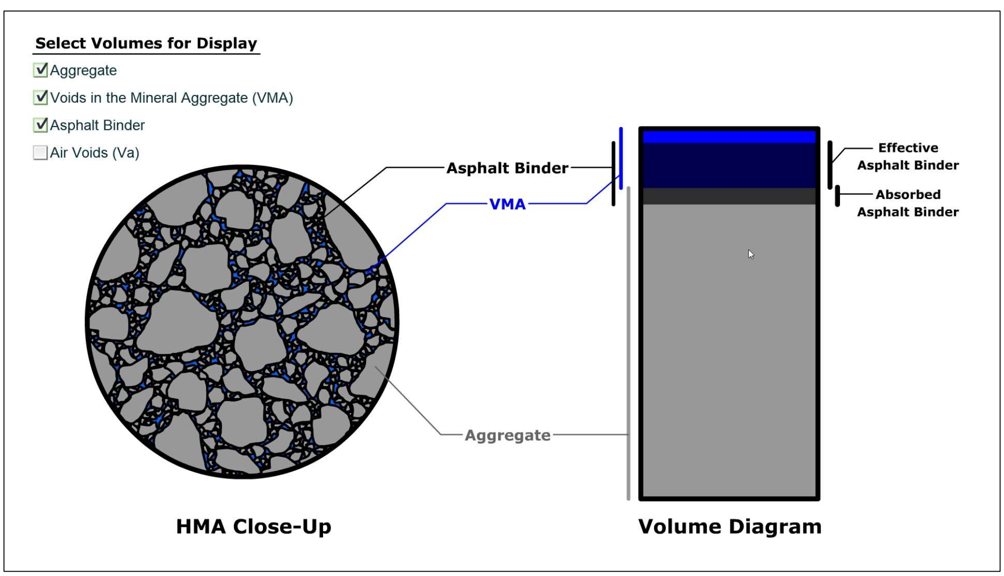

Image source:https://pavementinteractive.org/reference-desk/design/mix-design/hma-weight-volume-terms-and-relationships/

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Asphalt Mixture

The volumetric relationship

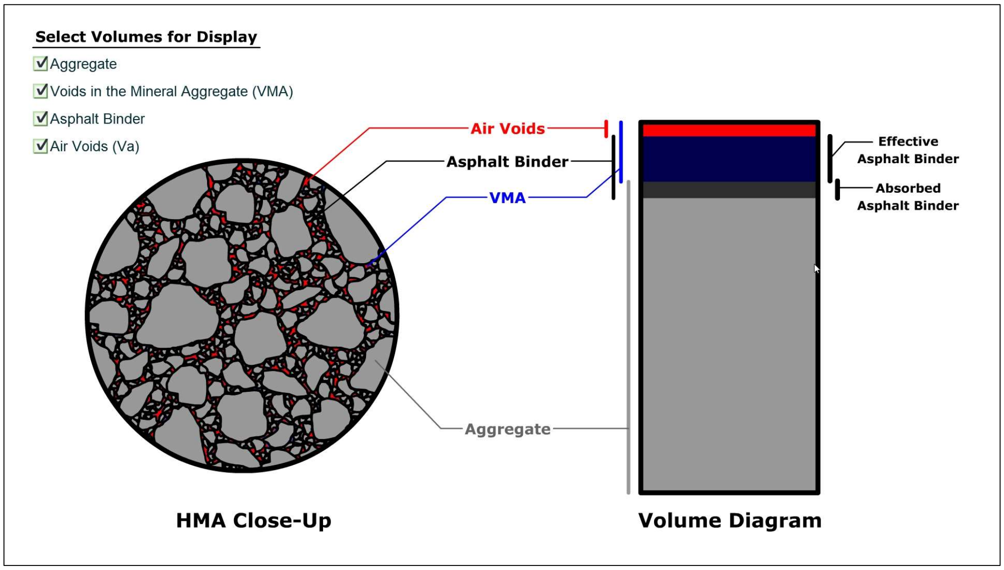

Image source:https://pavementinteractive.org/reference-desk/design/mix-design/hma-weight-volume-terms-and-relationships/

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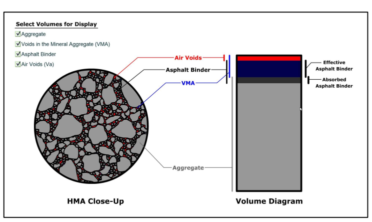
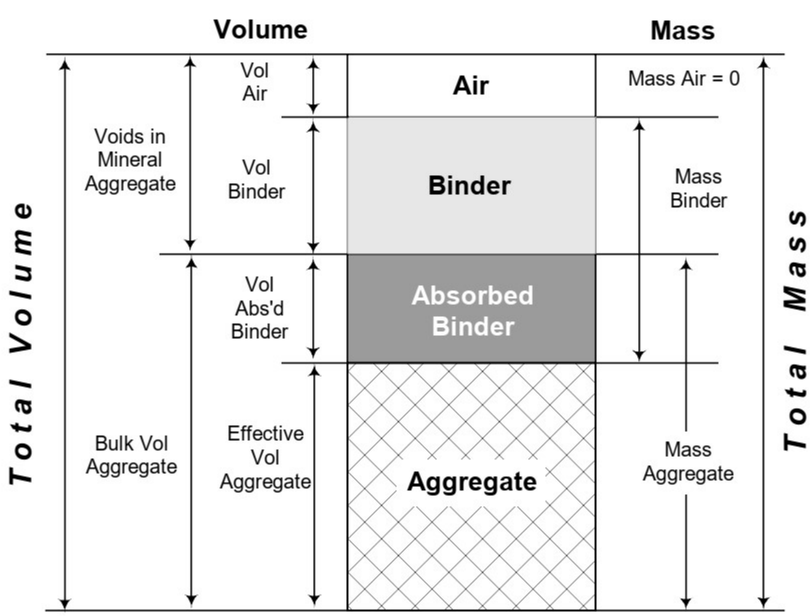
Volumetric analysis

Phase Diagram





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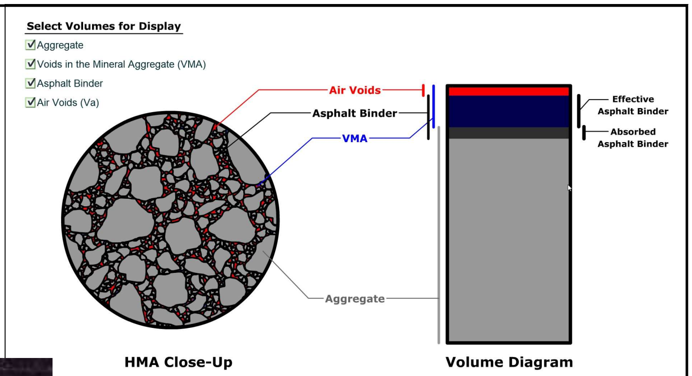
Asphalt Mixture

The volumetric relationship



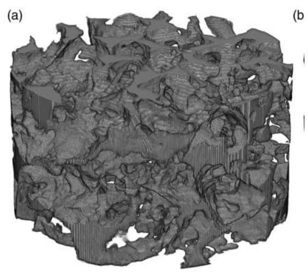


Figure 8. 3D connected air void structure of (a.) PA 11 and (b.) PA1

Image source:https://pavementinteractive.org/reference-desk/design/mix-design/hma-weight-volume-terms-and-relationships/

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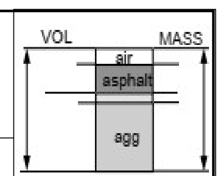
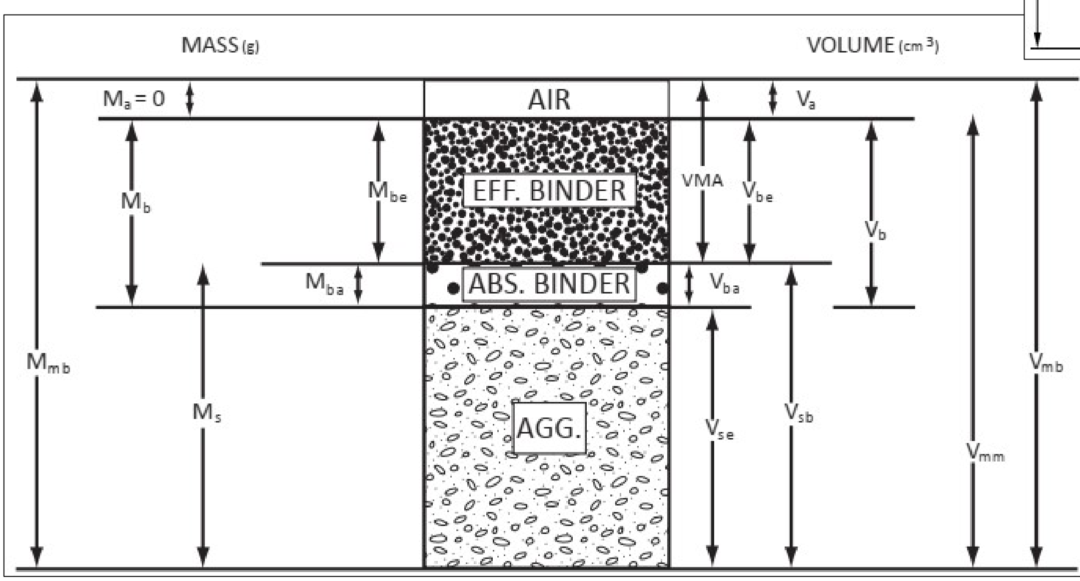
Volumetric analysis

Phase Diagram





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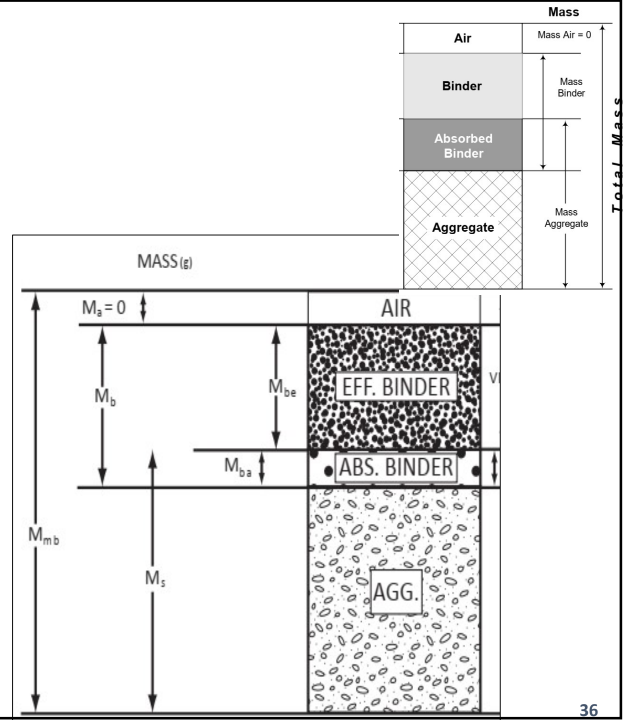
❑ The standard nomenclature for most volumetric properties uses: X_{YZ}

1. a beginning capital letter to identify the property type
   - *G - specific gravity,*
     M – mass,
     V – volume,
     P - percent
2. followed by a subscripted lowercase letter identifying the material
   - *a – air,*
     b – binder,
     s - stone (aggregate),
     m - mix
3. sometimes followed by a second subscripted lowercase letter giving more detail about the nature of the property.
   - a - absorbed (binder only),
     a - apparent (aggregate only),
     b – bulk,
     e – effective
     m - maximum



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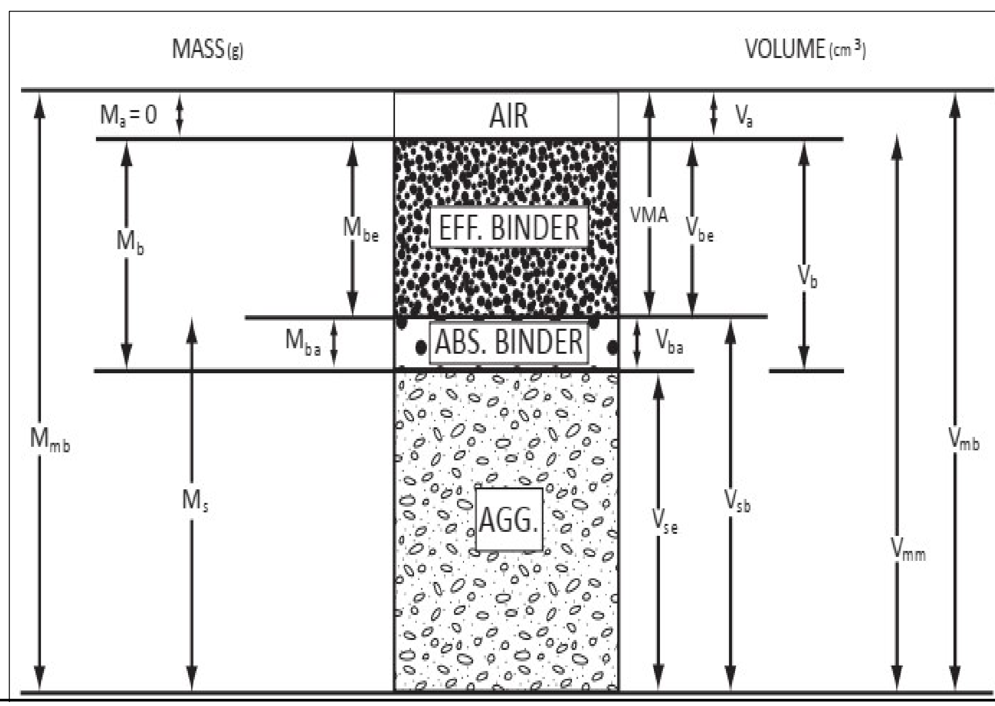

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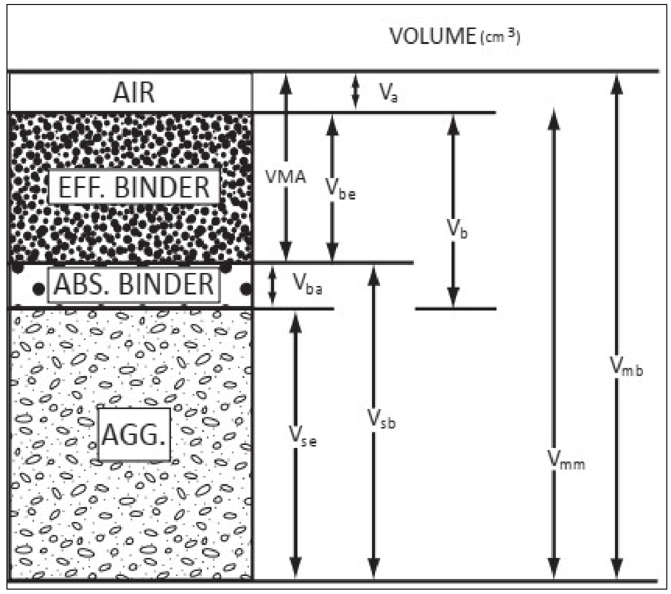
Phase Diagram

Terms

V_{mb}	Total volume of the compacted specimen
V_{mm}	Total volume of the loose mixture
V_a	Volume of air voids
V_b	Volume of asphalt binder
V_{be}	Volume of effective asphalt binder
V_{ba}	Volume of absorbed asphalt binder
V_{sb}	Volume of aggregate
V_{se}	Effective volume of aggregate
VMA	Voids in the Mineral Aggregate



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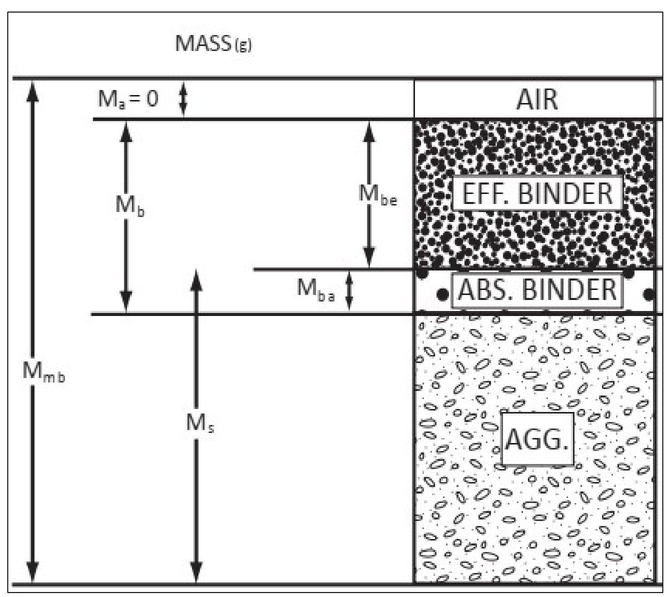
Phase Diagram

Terms

M_{mb}	Total weight of the compacted specimen
M_a	Total weight of air voids (= ZERO)
M_b	Total weight of asphalt binder
M_{be}	Total weight of effective asphalt binder
M_{ba}	Total weight of absorbed asphalt binder
M_s	Total weight of aggregate
V_{se}	Effective volume of aggregate



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Volumetric analysis Procedures

The measurements needed for Volumetric analysis are:

1. Measure the bulk specific gravities of the coarse aggregate and fine aggregate
   - *(AASHTO T 85 or ASTM C 127) and of the fine aggregate (AASHTO T 84 or ASTM C 128).*
2. 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).*
3. Calculate the bulk specific gravity of the aggregate combination (Blend) in the paving mixture.
4. Measure the maximum specific gravity of the loose paving mixture
   - *(ASTM D 2041 or AASHTO T209).*
5. Measure the bulk specific gravity of the compacted paving mixture
   - *(ASTM D 1188/D 2726 or AASHTO T166).*

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Volumetric analysis Procedures

The calculations needed for Volumetric analysis are:

6. Calculate the effective specific gravity of the aggregate.
7. Calculate the maximum specific gravity at other asphalt contents.
8. Calculate the asphalt absorption of the aggregate.
9. Calculate the effective asphalt content of the paving mixture.
10. Calculate the percent voids in the mineral aggregate (VMA) in the compacted paving mixture.
11. Calculate the percent air voids (AV) in the compacted paving mixture.
12. Calculate the percent voids filled with asphalt (VFA) in the compacted paving mixture

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HMA Mix Design

Asphalt Mixtures Volumetric

Specific Gravity for asphalt binder

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Introduction

Volumetric properties

- The relationship between mass and volume is determined by the material's **specific gravity (G)**
- Specific gravity is a dimensionless number defined as the ratio of the density of a material to the density of water (assumed to be 1.000 g/cm3 at temperatures used in asphalt testing)

$$G = \frac{\frac{m}{v}}{\rho} = \frac{m}{v \times \rho}$$

- where
  - G = specific gravity
  - m = mass of the material
  - v = volume of the material
  - ρ = density of water

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Asphalt Binder Specific Gravity (G_b)

ASTM D70

- Summary of Test Method
  - *The sample is placed in a calibrated pycnometer*
  - *The pycnometer and sample are weighed, then the remaining volume is filled with water.*
  - *The filled pycnometer is brought to the test temperature and weighed.*
  - *The density of the sample is calculated from its mass and the mass of water displaced by the sample in the filled pycnometer*

- Calculate the S.G. as indicated in the following equ:
  - $S.G = \frac{(C-A)}{[(B-A) - (D-C)]}$ *, Where*
    - A = mass of pycnometer (plus stopper),
    - B = mass of pycnometer filled with water,
    - C = mass of pycnometer partially filled with asphalt
    - D = mass of pycnometer plus asphalt plus water.
  - $Density = S.G \times \gamma_w$, *Where*
    - γ_w = density of water at the test temperature (At 25°C, γ_w = 997.0 kg/m^3)
- Binder specific gravity typically ranges from **1.00 to 1.05**

Example

Table 1: Tests Results of Marshall Lab Trial Mixes

Bulk Specific Gravity of Combined Aggregate	*(Gsb)* =	2.723
Effective Specific Gravity of Combined Aggregate	*(Gse)* =	2.779
Absorbed Asphalt by Weight of Aggregate	*(Pba)* =	0.75%
Specific Gravity of Bitumen	*(Gb)* =	1.019

HMA Mix Design

Asphalt Mixtures Volumetric

Specific Gravity for Aggregates

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Aggregate Specific Gravity

- Due to permeable voids in aggregates, three types of S. G. are defined
  - *Apparent (G_{sa})*
    - the ratio of the oven-dry mass of a unit volume of aggregate (including only the impermeable void volumes) to the mass of the same volume of water
  - *Aggregate Bulk Specific Gravity (G_{sb})*
    - the ratio of the oven-dry mass of a unit volume of aggregate (including both the impermeable and water-permeable void volumes) to the mass of the same volume of water
  - *Effective (G_{se})*
    - The ratio of the oven-dry mass of a unit volume of aggregate (including both the impermeable void volumes and the water permeable voids not filled with absorbed asphalt) to the mass of the same volume of water

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Aggregate Spe

Terms

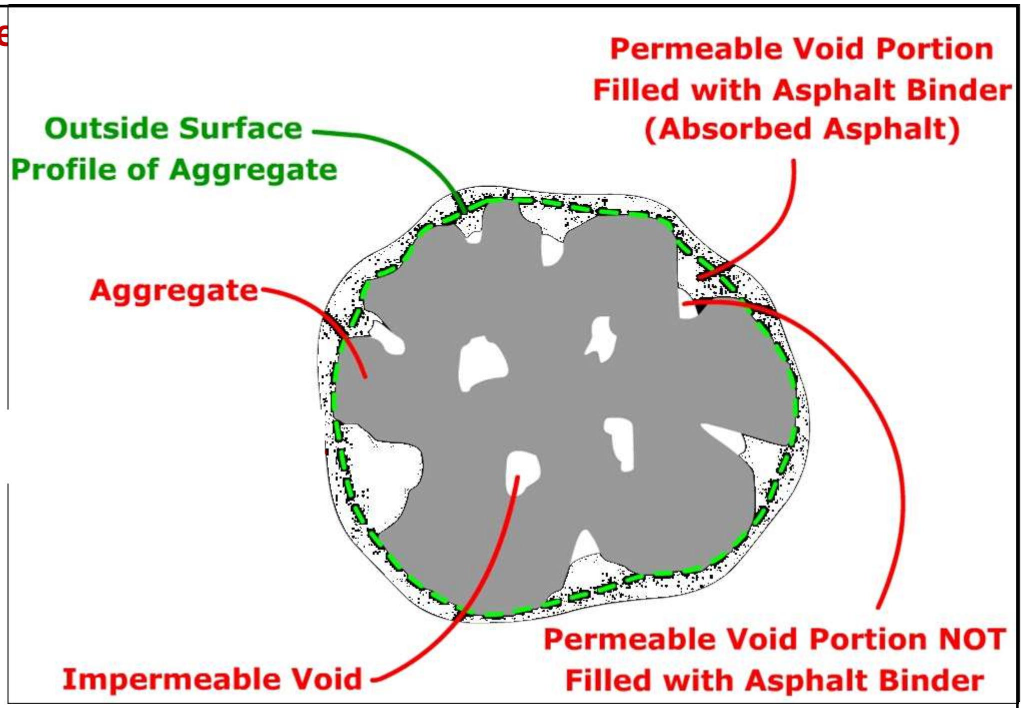

Image source: https://pavementinteractive.org/reference-desk/testing/aggregate-tests/coarse-aggregate-specific-gravity/

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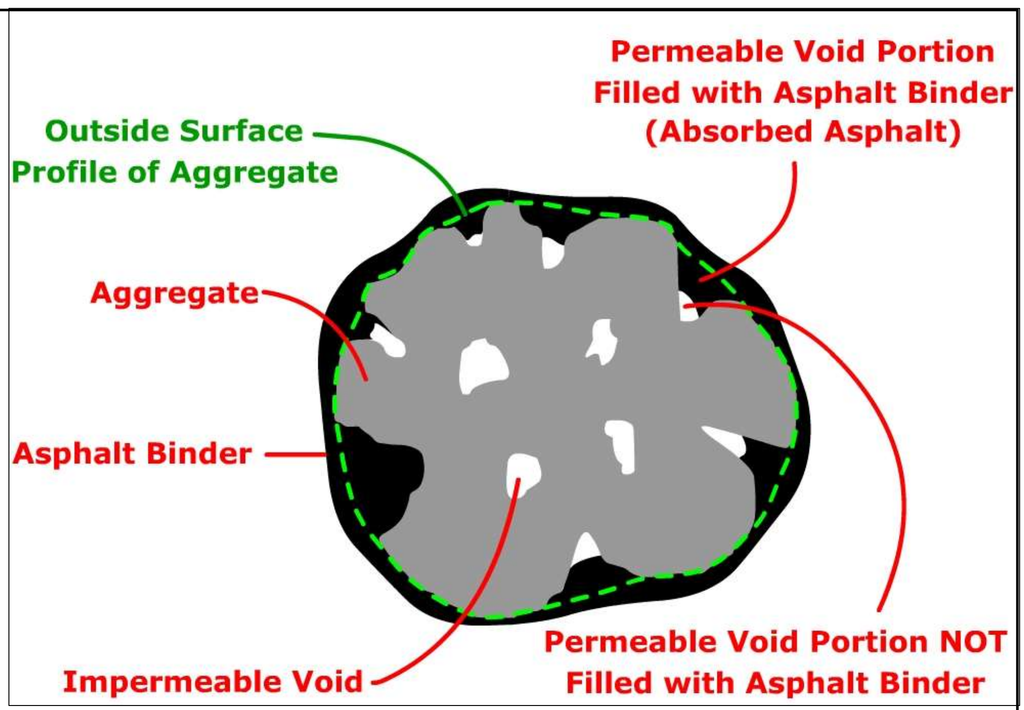

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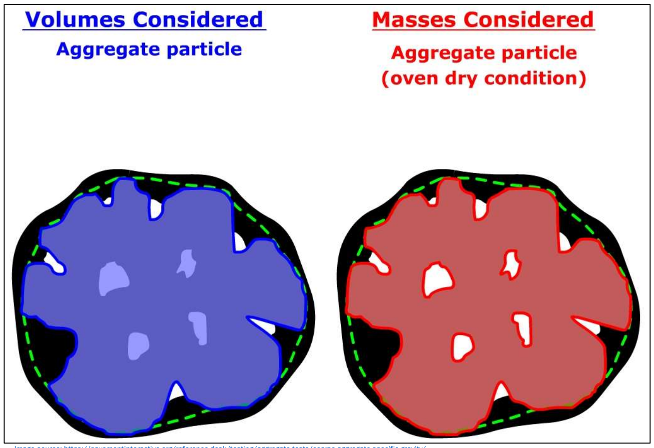
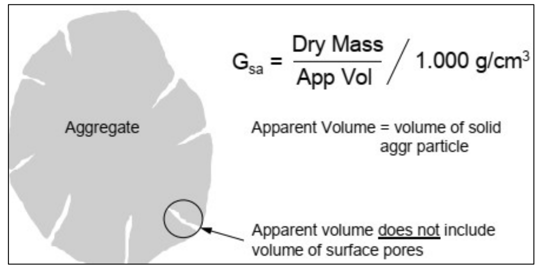
Aggregate Specific Gravity

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





$$G_{sa} = \frac{W_s}{V_s \gamma_w} = \frac{M_s}{V_s \rho_w}$$

Image source: https://pavementinteractive.org/reference-desk/testing/aggregate-tests/coarse-aggregate-specific-gravity/

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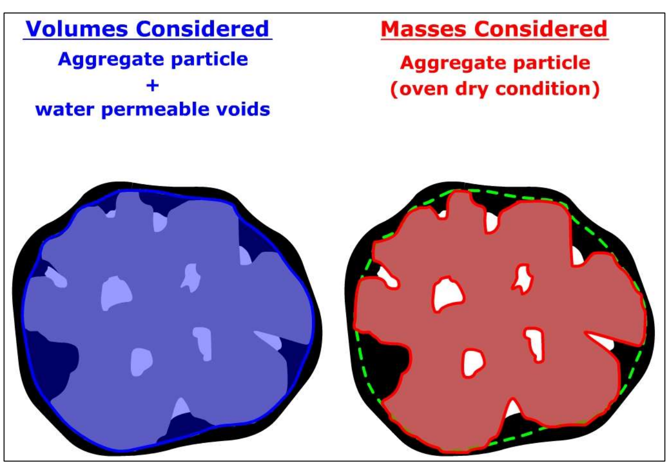
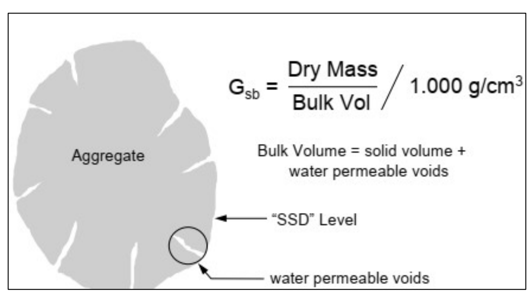
Aggregate Specific Gravity

Bulk Specific Gravity, G_{sb}

- The ratio of the mass in air of a unit volume of a permeable material to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature.





$$G_{sb} = \frac{W_s}{(V_s + V_{pp})\gamma_w} = \frac{M_s}{(V_s + V_{pp})\rho_w}$$

Image source: https://pavementinteractive.org/reference-desk/testing/aggregate-tests/coarse-aggregate-specific-gravity/

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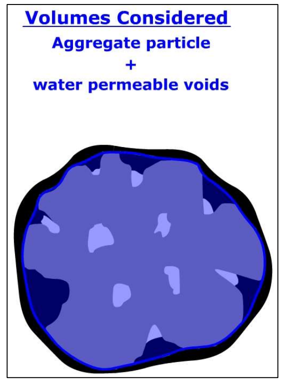
Aggregate Specific Gravity

Effective Specific Gravity, G_{se}

- ❑ Aggregate absorb some asphalt cement (AC).
  - ➢ *G_{sa} assumes ALL permeable pores absorb AC ($V_{ap} = V_{pp}$)*
  - ➢ *G_{sb} assumes NO permeable pores absorb AC ($V_{ap} = 0$)*
- ❑ Neither is correct



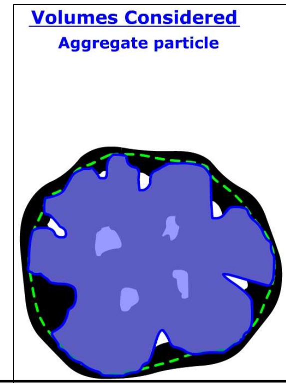


Image source: https://pavementinteractive.org/reference-desk/testing/aggregate-tests/coarse-aggregate-specific-gravity/

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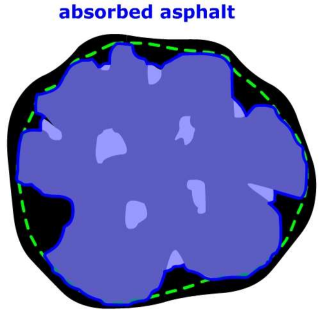
Aggregate Specific Gravity

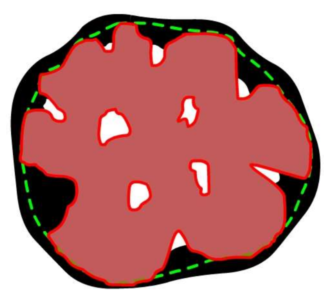
Effective Specific Gravity, G_{se}

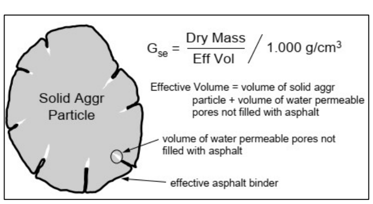
- ❑ G_{se} defined based on overall volume exclusive of those that absorb AC
- ❑ Effective Specific Gravity, G_{se}
  - ➢ The ratio of the mass in air of a unit volume of a permeable material (excluding voids permeable to asphalt) at a stated temperature to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature.
  - ➢ The G_{se} is determined using Theoretical Maximum Specific Gravity G_{mm} as will discussed later

Volumes Considered
Aggregate particle
+
water permeable voids
-
absorbed asphalt



Masses Considered
Aggregate particle
(oven dry condition)





$$G_{se} = \frac{W_s}{(V_s + V_{pp} - V_{ap})\gamma_w} = \frac{M_s}{(V_s + V_{pp} - V_{ap})\rho_w}$$

Image source: https://pavementinteractive.org/reference-desk/testing/aggregate-tests/coarse-aggregate-specific-gravity/

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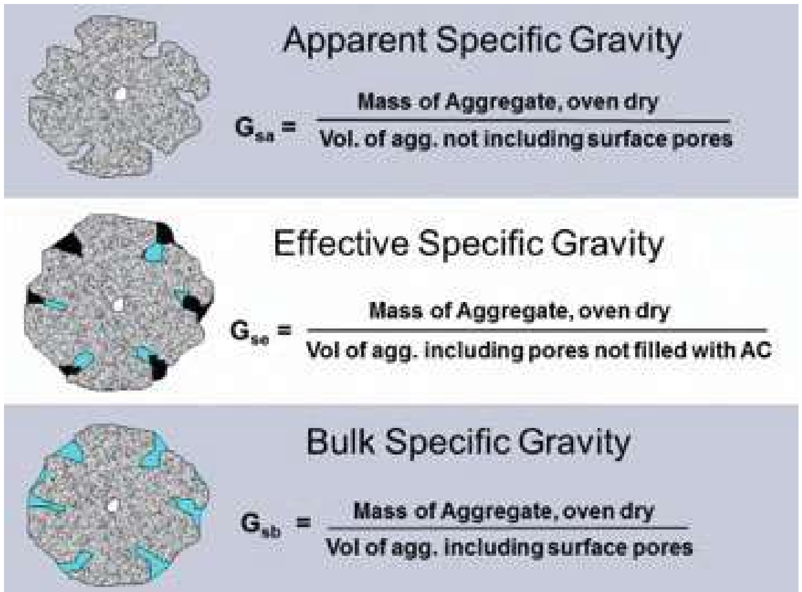
Aggregate Specific Gravity



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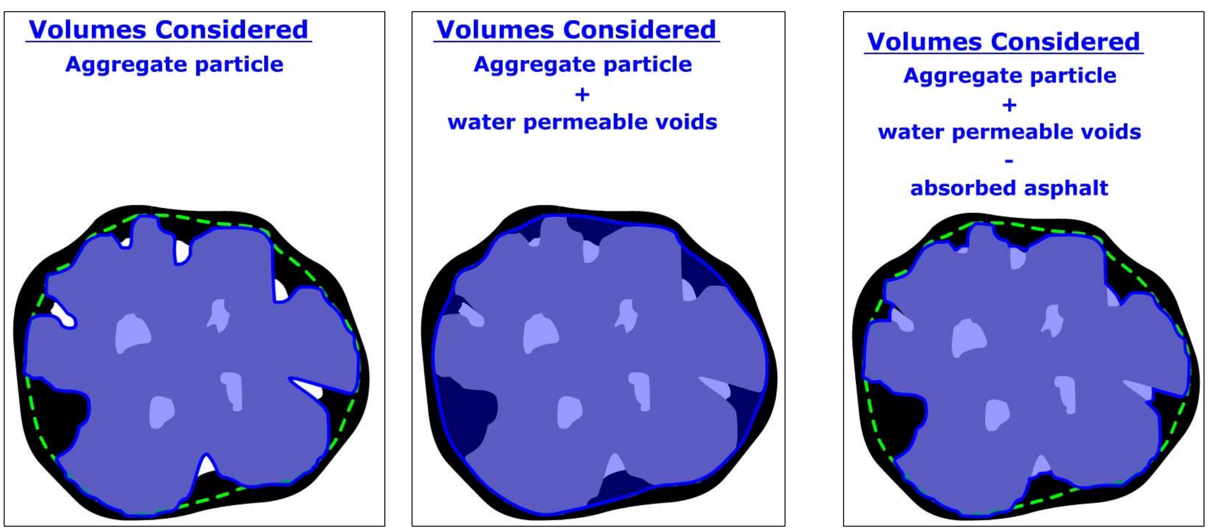
Aggregate Volumes



Apparent Volume | Bulk Volume | Effective Volume

60

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Aggregate Specific Gravity

- $G_{sb} < G_{se} < G_{sa}$
  - Since G_{sa} is intended to only measure the sp. gr. Of the solid volume, then it will be the highest of the 3 agg. sp. Gravities
  - Since G_{sb} includes the void volume, then it will be the lowest
  - Since G_{se} includes only the void volume that do not absorb asphalt, then it lies between G_{sa} and G_{sb}
- The specific gravity of aggregates normally used in road construction ranges from about 2.5 to 3.0 with an average of about 2.68.
- Water absorption shall not be more than 0.6 per unit by weight

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Aggregate Specific Gravity

Coarse Aggregate Specific Gravity

- Determined in accordance with ASTM C 127
  - Wash **5 kg** of aggregate retained on **No. 4 sieve**.
  - Oven dry to a constant weight.
  - Soak in water for **24 hours**.
  - Decant water.
  - Use pre-dampened towel to get **SSD** condition, weigh and record (**B**)
  - Place the SSD sample in a wire basket, **submerge in water**, then the submerged weight is determined and recorded (**C**)
  - **Oven dry** the sample to a constant weight, weigh and record (A)

- A: Oven-dry wt. of agg.(g)
- B: SSD wt. of agg. (g)
- C: submerged wt. of SSD agg. In water (g

$$G_{sa} = \frac{A}{A-C}$$

$$G_{sb} = \frac{A}{B-C}$$

$$G_{s,\,SSD} = \frac{B}{B-C}$$

$$\text{Apsorption, \%} = \frac{(B-A)\times 100}{A}$$

62

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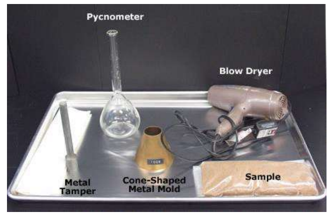
Aggregate Specific Gravity

***Fine** Aggregate Specific Gravity*



- Determined in accordance with ASTM C 128
  - Fill **flask with water** and record weight as (**B**)
  - Oven-dry **1000 g** of fine aggregate.
  - Soak in water for **24 hours**
  - Spread out and dry (warm air moving current) to **SSD**?
  - Add **500 g of SSD aggregate** (**D**) to pycnometer of **known volume** pre-filled with some water
  - Add more water and **agitate** until **air bubbles** have been **removed**
  - Fill to line and determine the **mass** of the **pycnometer**, **aggregate** and **water** (**C**)
  - Empty aggregate into pan and **dry to constant mass**
  - Determine **oven dry** mass (**A**)

$$G_{sa} = \frac{A}{B+A-C}$$

$$G_{sb} = \frac{A}{B+D-C}$$

$$G_{s,SSD} = \frac{D}{B+D-C}$$

$$\text{Apsorption, \%} = \frac{(D-A)\times 100}{A}$$

- A: Oven-dry wt. of agg. (g)
- B: wt. of flask filled with water (to mark), (g)
- C: wt. of flask + SSD specimen + water (to mark), (g)
- D: SSD wt. (500 ± 10 g)

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HMA Mix Design

Asphalt Mixtures Volumetric

Specific Gravity for Aggregate Blend

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Aggregate Specific Gravity for blend

Aggregate Blend

- A single aggregate source is generally **unlikely to meet gradation** requirements for Portland cement or asphalt concrete mixes
  - Thus, blending of aggregates from two or more sources would be required to satisfy the specifications.
- A trial-and-error process is generally used to determine the proportions
- The basic equation for blending is
  - $P_i = a \times Ai + B \times Bi + C \times Ci$;*where*
    - P_i = Percent blend materials passing sieve size I
    - A_i , B_i, C_i = Percent of aggregates from stockpiles A, B, C passing sieve size I
    - a,b, and c = devimal fraction by weight of aggregates from stockpiles A, B, C used in the blend

      * a + b+ c = 1.0

Aggregate Specific Gravity for blend

Composite G_{sb} for blend

- The average G_{sb} can be calculated as follows:

$$G_{sb} = \frac{P_1+P_2+P_3+\cdots...P_n}{\frac{P_1}{G_1}+\frac{P_2}{G_2}+\frac{P_3}{G_3}+\cdots...\frac{P_n}{G_n}+}, \textit{ where}$$

  - G_{sb} = bulk (dry) specific gravity of the aggregate
  - P_1, P_2, P_3 , P_n = Percentages by weight of aggregates 1, 2, through n
  - G_1, G_2, G_3 , G_n = P_1, P_2, P_3 , P_n = Percentages by weight of aggregates 1, 2, through n

Aggregate Specific Gravity for blend

Absorption (A) for the aggregate blend

- The absorptiveness of aggregate is of significant interest to the mixture designer and specifier.
  - *Absorption can be an indicator regarding aggregate quality along with increased binder demand.*
- The binder absorption is ***typically 40 –80 percent*** of the water absorption rate
- The water absorption rate is calculated by the following equation as outlined in AASHTO T 85

$$Absorption, \% = \frac{B-A}{A} \times 100$$

  - A = mass of the oven-dry test sample
  - B = mass of the saturated surface-dry sample

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Aggregate Specific Gravity for blend

Absorption (A) for the aggregate blend

- The average water absorption for the total aggregate blend as shown in AASHTO T 85 is calculated as follows

$$Absorption\ \% = \frac{P_1 \times A_1 + P_2 \times A_2 + \cdots ... P_n \times A_n}{100}, \text{ where}$$

  - P_1, P_2, P_n = Percentages by weight of aggregates 1, 2, through n
  - A_1, A_2, A_n = absorption of aggregates 1, 2, through n

75

75

Aggregate Identification		Coarse Agg. 1	Coarse Agg. 2	Medium Agg.	Medium -Fine Agg.	Fine Agg.
		(Basalt)			(Mixed)	
		حصوية 1	حصوية 2	عدسية	سمسمية	ناعمة
		(بازلت)			(خليط)	
Test Name		Test Result				
- Sieve Analysis: -		% Passing by Weight				
Sieve Number (Size, mm):	1" (25)	100	100	100	100	100
	3/4" (19)	99	100	100	100	100
	1/2" (12.5)	1	54	100	100	100
	3/8" (9.5)	1	11	80	98	100
	No. 4 (4.75)	1	1	14	55	98
	No. 8 (2.36)	1	1	2	4	86
	No. 20 (0.850)	1	1	2	3	47
	No. 50 (0.300)	1	1	1	3	27
	No. 80 (0.180)	1	1	1	2	21
	No. 200 (0.075)	0.4	0.6	0.9	1.9	13.5
- Specific Gravity (SG):	Bulk SG. (Oven Dry)	2.748	2.741	2.736	2.718	2.703
	Bulk SG. (SSD)	2.797	2.791	2.788	2.782	2.773
	Apparent SG.	2.890	2.886	2.887	2.903	2.907
- Water Absorption, %		1.8	1.8	1.9	2.3	2.6

And the obtained combined grading was as follows: -

Sieve No. (Size, mm)		% Passing by Weight			
		Combined Grading	Specification Limits		
1"	(25)	100	100		
3/4"	(19)	99.9	90	-	100
1/2"	(12.5)	84.8	71	-	90
3/8"	(9.5)	72.4	56	-	80
No. 4	(4.75)	47.1	35	-	56
No. 8	(2.36)	29.9	23	-	38
No. 20	(0.850)	16.8	13	-	27
No. 50	(0.300)	10.0	5	-	17
No. 80	(0.180)	7.8	4	-	14
No. 200	(0.075)	5.2	2	-	8

Bulk Specific Gravity of Combined Aggregate	(Gsb) =	2.723
Effective Specific Gravity of Combined Aggregate	(Gse) =	2.779
Absorbed Asphalt by Weight of Aggregate	(Pba) =	0.75%

Hot Bin Components			Hot Bin Proportions, %
- Coarse Agg. 1	(Hot Bin 1)	حصوية 1	7.0
- Coarse Agg. 2	(Hot Bin 2)	حصوية 2	18.0
- Medium Agg.	(Hot Bin 3)	عدسية	21.0
- Medium-Fine Agg.	(Hot Bin 4)	سمسمية	21.0
- Fine Agg.	(Hot Bin 5)	ناعمة	33.0
- Total		المجموع	100.0

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Hot Bin Components			Hot Bin Proportions, %
- Coarse Agg. 1	(Hot Bin 1)	حصوية 1	7.0
- Coarse Agg. 2	(Hot Bin 2)	حصوية 2	18.0
- Medium Agg.	(Hot Bin 3)	عدسية	21.0
- Medium-Fine Agg.	(Hot Bin 4)	سمسمية	21.0
- Fine Agg.	(Hot Bin 5)	ناعمة	33.0
- Total		المجموع	100.0

$$G_{sb} = \frac{P_1 + P_2 + P_3 + \cdots \ldots P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3} + \cdots \ldots \frac{P_n}{G_n} +}$$

Aggregate Identification		Coarse Agg. 1	Coarse Agg. 2	Medium Agg.	Medium -Fine Agg.	Fine Agg.
		(Basalt)			(Mixed)	
		حصوية 1	حصوية 2	عدسية	سمسمية	ناعمة
		(بازلت)			(خليط)	
Test Name		Test Result				
- Specific Gravity (SG):	Bulk SG. (Oven Dry)	2.748	2.741	2.736	2.718	2.703
	Bulk SG. (SSD)	2.797	2.791	2.788	2.782	2.773
	Apparent SG.	2.890	2.886	2.887	2.903	2.907
- Water Absorption, %		1.8	1.8	1.9	2.3	2.6

Bulk Specific Gravity of Combined Aggregate	(Gsb) =	2.723
Effective Specific Gravity of Combined Aggregate	(Gse) =	2.779

$$G_{sb} = \frac{7 + 18 + 21 + 21 + 33}{\frac{7}{2.748} + \frac{18}{2.741} + \frac{21}{2.736} + \frac{21}{2.718} + \frac{33}{2.703}}$$

$G_{sb} = 2.723$

77

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Hot Bin Components			Hot Bin Proportions, %
- Coarse Agg. 1	(Hot Bin 1)	حصمة 1	7.0
- Coarse Agg. 2	(Hot Bin 2)	حصمة 2	18.0
- Medium Agg.	(Hot Bin 3)	عدسية	21.0
- Medium-Fine Agg.	(Hot Bin 4)	سمسمية	21.0
- Fine Agg.	(Hot Bin 5)	ناعمة	33.0
- Total		المجموع	100.0

$$Absorption\ \% = \frac{P_1 \times A_1 + P_2 \times A_2 + \cdots \ldots P_n \times A_n}{100}$$

Aggregate Identification		Coarse Agg. 1	Coarse Agg. 2	Medium Agg.	Medium -Fine Agg.	Fine Agg.
		(Basalt)			(Mixed)	
		حصمة 1	حصمة 2	عدسية	سمسمية	ناعمة
		(بازلت)			(خليط)	
Test Name		Test Result				
- Specific Gravity (SG):	Bulk SG. (Oven Dry)	2.748	2.741	2.736	2.718	2.703
	Bulk SG. (SSD)	2.797	2.791	2.788	2.782	2.773
	Apparent SG.	2.890	2.886	2.887	2.903	2.907
- Water Absorption, %		1.8	1.8	1.9	2.3	2.6

Bulk Specific Gravity of Combined Aggregate	(Gsb) =	2.723
Effective Specific Gravity of Combined Aggregate	(Gse) =	2.779

$$Absorption\ \% = \frac{7 \times 1.8 + 18 \times 1.9 + 21 \times 1.9 + 21 \times 2.3 + 33 \times 2.6}{100} = 2.2$$

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HMA Mix Design

Asphalt Mixtures Volumetric

Specific Gravity for Asphalt Mixture

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HMA Mix Design

Asphalt Mixtures Volumetric

Specific Gravity for Asphalt Mixture

Bulk Specific Gravity Gmb

80

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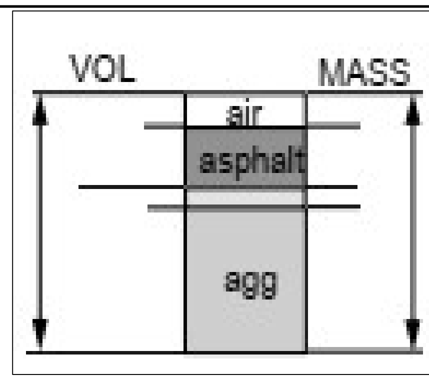
Specific Gravity for Asphalt Mixture

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, Gmb,
  - *the mass of the asphalt and aggregate mixture divided by the volume, including the air voids*
- G_{mb} is applicable to any laboratory- or field-compacted specimen including cores, beams, slabs, etc.
- The bulk specific gravity test may be performed as soon as the freshly compacted specimens have cooled to room temperature.
- This test is performed according to AASHTO T166



Compacted Mixture

81

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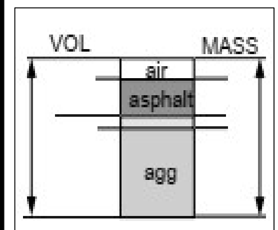
Specific Gravity for Asphalt Mixture

Bulk Specific Gravity G_{mb}



Videos source: https://www.youtube.com/watch?v=U6-8C1hRdDk

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Specific Gravity for Asphalt Mixture

Bulk Specific Gravity G_{mb}

- ❑ Determine the weight of the compacted specimen in air (***A***).
- ❑ Immerse specimen in water (25 °c) for 3 – 5 minutes and record its weight (***C***)
- ❑ Surface dry the specimen and determine SSD weight (***B***).
- ❑ Bulk S.G. = G_{mb} = [***A*** / (***B-C***)]
- ❑

$$G_{\text{mb}} = \frac{W_{dry}}{W_{ssd} - W_{sub}}$$

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HMA Mix Design

Asphalt Mixtures Volumetric

Specific Gravity for Asphalt Mixture

Theoretical Maximum Specific Gravity G_{mm}

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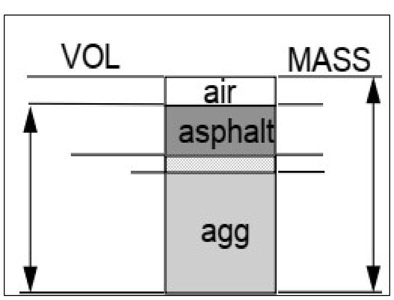
Specific Gravity for Asphalt Mixture

Theoretical Maximum Specific Gravity Gmm

- Defined as
  - *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, Gmm,
  - *The mass of the asphalt and aggregate mixture (LOOSE MIXTURE) divided by the volume, not including the air voids*



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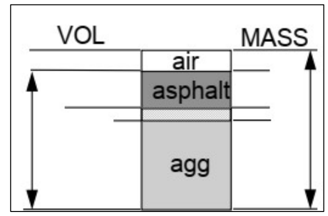
Specific Gravity for Asphalt Mixture

Theoretical Maximum Specific Gravity Gmm



- ❑ Theoretical maximum specific gravity is a critical HMA characteristic
  - ➢ *because it is used to calculate percent air voids in compacted HMA.*
  - ➢ *This calculation is used both in mix design and determination of in-place air voids in the field.*
- ❑ 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)*

Loose Mixture

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Specific Gravity for Asphalt Mixture

Theoretical Maximum Specific Gravity G_{mm} [AASHTO T209]

- ❑ Theoretical maximum specific gravity is determined by taking a sample of loose HMA (i.e., not compacted), weighing it and then determining its volume by calculating the volume of water it displaces . Theoretical maximum specific gravity is then the sample weight divided by its volume.
- ❑ Procedures
  - ➢ *If the mix contain absorptive aggregates, place loose mix in oven for (4hrs) at mixing temp. so that AC is completely absorbed by aggregate prior to testing.*
  - ➢ *Separate particles.....Cool to room temp......place in container....determine dry weight (**A**).*
  - ➢ *Fill pycnometer with water & take wt. (**D**).*
  - ➢ *Put the asphalt mix sample in the pycnometer & add water to fill it @25 ℃.*
  - ➢ *Removed entrapped air by vacuuming until residual pressure manometer reads 30 mmHg or less. Maintain this pressure for 5 to 15 minutes. Agitate container while vacuuming.*
- ❑ Fill pycnometer with water....dry outside.....take wt. (***E***) = Wt of Pycnometer + Asphalt mix sample + water.

$$G_{mm} = TMD = [\,A / (A + D - E)]$$

- ❑ If test is conducted on 3 specimens mixed at or near optimum....Average 3 results....then calculate effective S.G. (G_{se}) of aggregate..... Then calculate G_{mm} for the remaining mixes with different AC contents.
- ❑ If Rice S.G. is found for each mix with different AC..... Then calculate G_{se} of aggregates in each case.... Then calculate Average G_{se} ...... then calculate Gmm values using the average for all five mixes

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Specific Gravity for Asphalt Mixture

Theoretical Maximum Specific Gravity G_{mm}

Rice Method

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

Specific Gravity for Asphalt Mixture

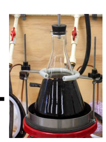
Theoretical Maximum Specific Gravity Gmm

Three specimens prepared at specified binder content

No.1

No.2

No.3



Gmm Specimen No.1

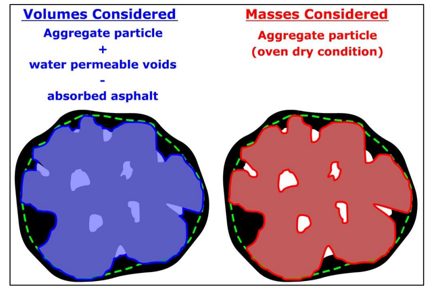
Gmm Specimen No.2

Gmm Specimen No.3

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

Aggregate Specific Gravity (G_b)

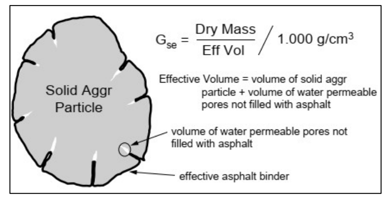
Effective Specific Gravity, G_{se}



- ❑ 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



$$G_{se} = \frac{W_s}{(V_s + V_{pp} - V_{ap})\gamma_w} = \frac{M_s}{(V_s + V_{pp} - V_{ap})\rho_w}$$

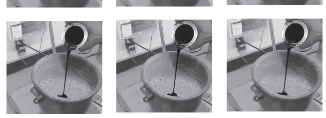
Image source: https://pavementinteractive.org/reference-desk/testing/aggregate-tests/coarse-aggregate-specific-gravity/

Step C : Preparation of Marshall Specimen

- ❑ C-4: Prepare three specimens at five different binder contents

Estimated O.B.C -1.0%

Estimated O.B.C - 0.5%



Estimated Optimum binder content (O.B.C)

Estimated O.B.C + 0.5%

Estimated O.B.C +1.0%

Specific Gravity for Asphalt Mixture

Maximum Theoretical Specific Gravity, G_{mm}

- 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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Specific Gravity for Asphalt Mixture

Example

- If the specific gravity of the asphalt cement used in a sample of asphalt concrete mix is 1.01, the maximum specific gravity of the mix is 2.50, and the mix contains 6.5% by weight of asphalt cement, Determine
  - *The effective specific gravity of aggregates (G_{se})*
  - *The maximum specific gravity (G_{mm}) at 5.5%, 6.0%, 7.0%, and 7.5% binder content*

Specific Gravity for Asphalt Mixture

Solution

- If the specific gravity of the asphalt cement used in a sample of asphalt concrete mix is 1.01, the maximum specific gravity of the mix is 2.50, and the mix contains 6.5% by weight of asphalt cement, Determine
  - *The effective specific gravity of aggregates (G_{se})*
  - *The maximum specific gravity (G_{mm}) at 5.5%, 6.0%, 7.0%, and 7.5% binder content*

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

Specific Gravity for Asphalt Mixture

Example

Gse for mix				
Effective Specific Gravity of Aggregate	Gmm	2.58	Pb	6.5
	Pmm	100	Gb	1.010
	Gse	2.89		

Gmm @ Pb = 5.5						
Maximum Specific Gravity of Mixtures with Different Asphalt Contents	Pmm	100	Pb (%)	5.50	Gb	1.010
	Ps (%)	94.50	Gse	2.89258		
	Gmm	2.62				

Gmm @ Pb = 6						
Maximum Specific Gravity of Mixtures with Different Asphalt Contents	Pmm	100	Pb (%)	6.00	Gb	1.010
	Ps (%)	94.00	Gse	2.89		
	Gmm	2.60				

Gmm @ Pb = 7						
Maximum Specific Gravity of Mixtures with Different Asphalt Contents	Pmm	100	Pb (%)	7.00	Gb	1.010
	Ps (%)	93.00	Gse	2.89		
	Gmm	2.56				

Gmm @ Pb = 7.5						
Maximum Specific Gravity of Mixtures with Different Asphalt Contents	Pmm	100	Pb (%)	7.50	Gb	1.010
	Ps (%)	92.50	Gse	2.89		
	Gmm	2.54				

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HMA Mix Design

Asphalt Mixtures Volumetric

Volumetric Performance Parameters

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Asphalt Mixture

The volumetric relationship HMA

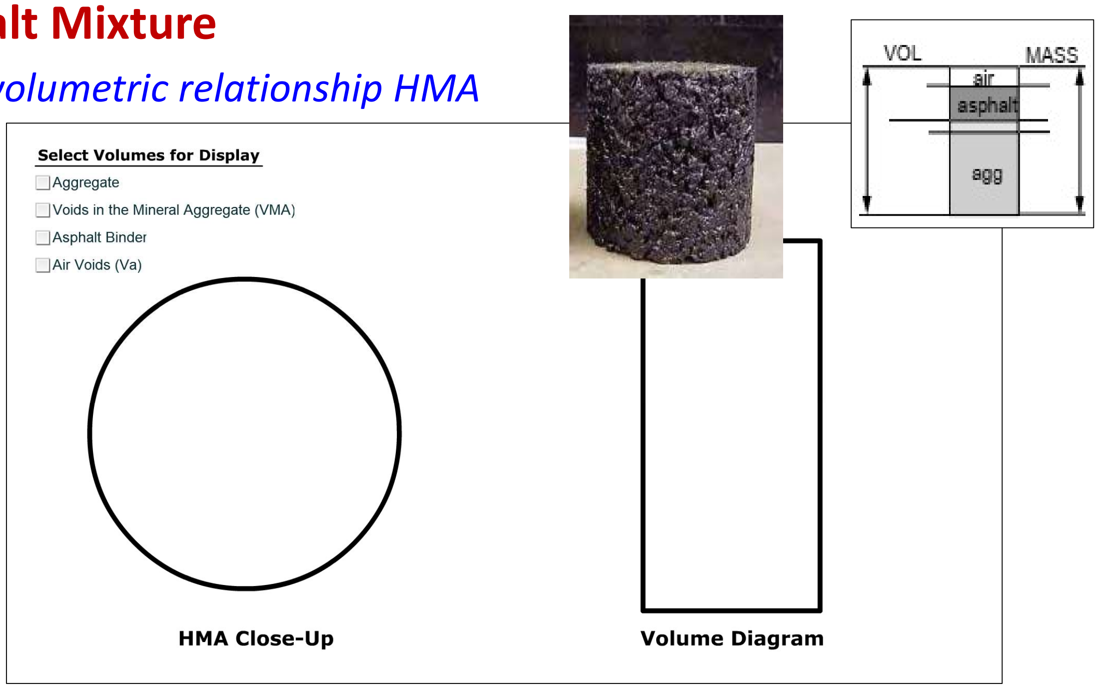

Image source:https://pavementinteractive.org/reference-desk/design/mix-design/hma-weight-volume-terms-and-relationships/

100

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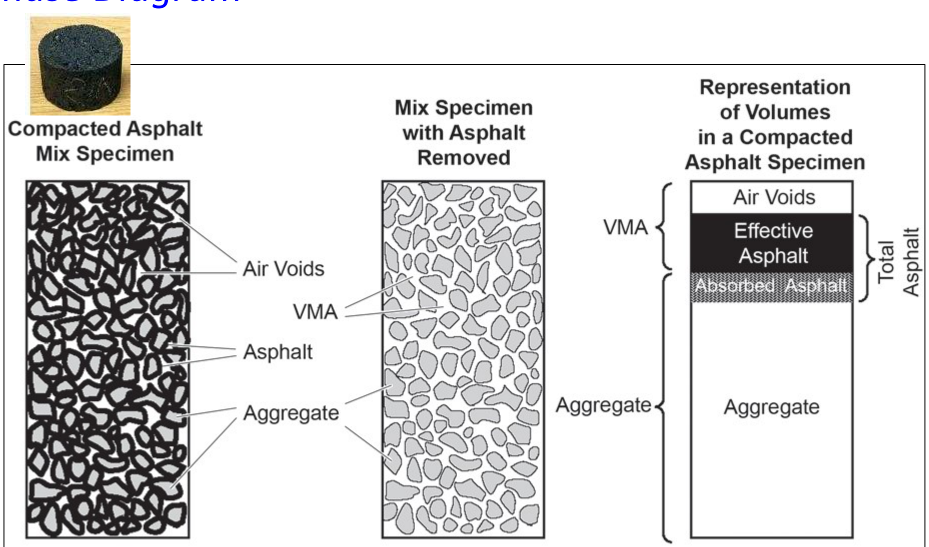
Volumetric analysis

Phase Diagram



Note: For simplification, the volume of absorbed asphalt is not shown.

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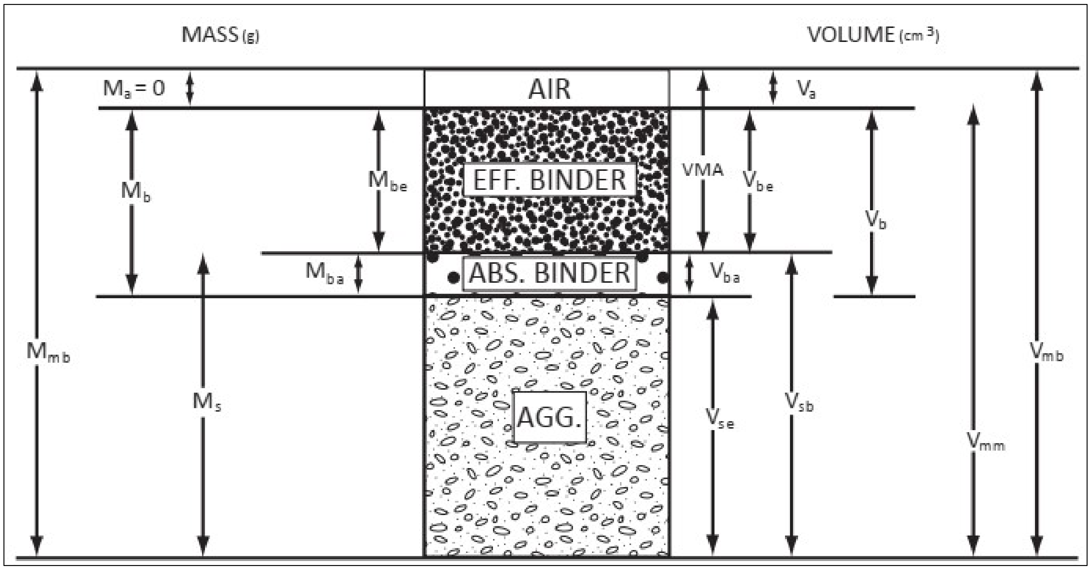
Volumetric analysis

Phase Diagram



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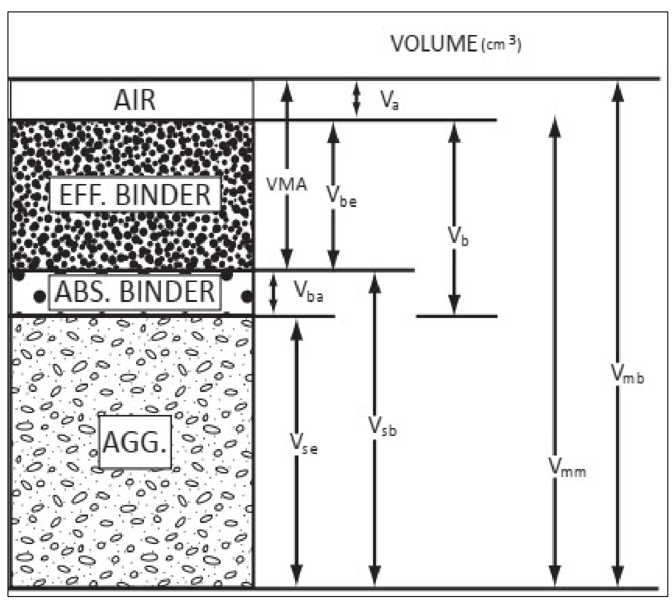
Phase Diagram

Terms

V_{mb}	Total volume of the compacted specimen
V_{mm}	Total volume of the loose mixture
V_a	Volume of air voids
V_b	Volume of asphalt binder
V_{be}	Volume of effective asphalt binder
V_{ba}	Volume of absorbed asphalt binder
V_{sb}	Volume of aggregate
V_{se}	Effective volume of aggregate
VMA	Voids in the Mineral Aggregate



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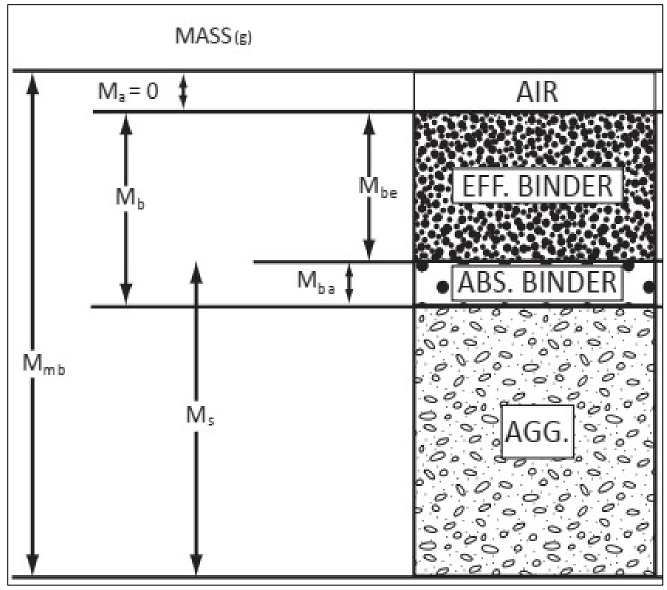
Phase Diagram

Terms

Mmb	Total weight of the compacted specimen
Ma	Total weight of air voids (= ZERO)
Mb	Total weight of asphalt binder
Mbe	Total weight of effective asphalt binder
Mba	Total weight of absorbed asphalt binder
Ms	Total weight of aggregate
Vse	Effective volume of aggregate



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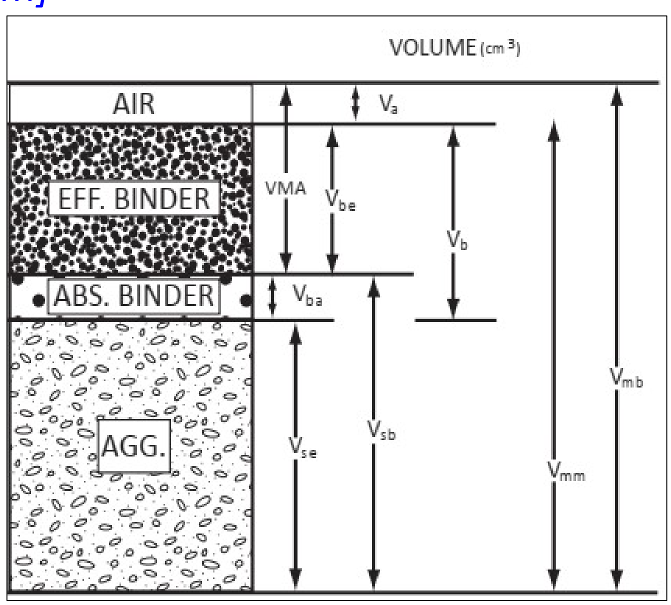
Mixture volumetric parameters

Percent Air Voids [P_a or V_a or VTM]

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



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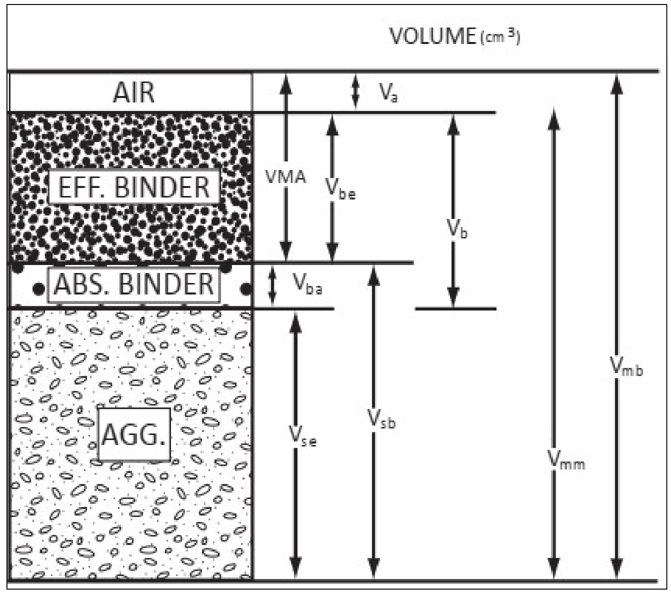
Mixture volumetric parameters

Voids in the Mineral Aggregate (VMA)

- Defined as
  - *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,*
- VMA represents the volume of air voids and effective (non-absorbed) asphalt binder
- Expressed as
  - *A percent of the total volume of the compacted paving mixture.*
  - $VMA = 100 - \frac{G_{mb} \times P_s}{G_{sb}}$



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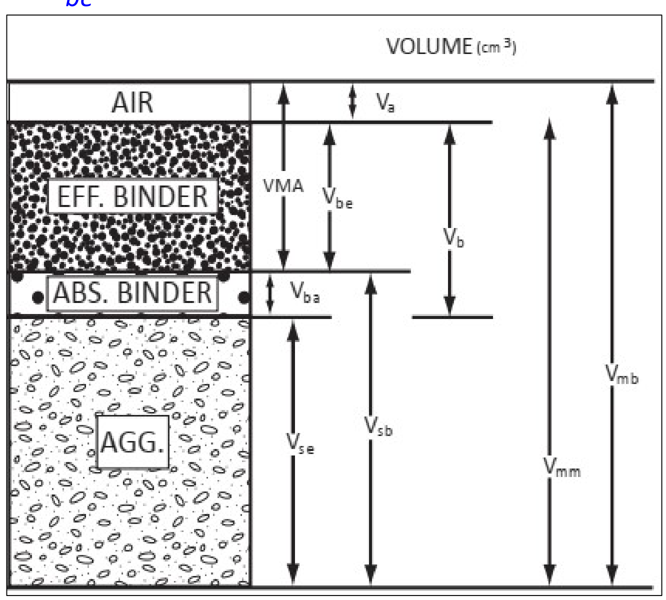
Mixture volumetric parameters

Voids Filled with Asphalt (VFA) or V_{be}

- Defined as
  - *The percentage of the VMA filled with effective (nonabsorbed) asphalt binder*
- Determined as
  - $VFA = 100 \times \frac{V_{be}}{V_{be} + _{va}}$
  - $VFA = 100 \times \frac{VMA - V_a}{VMA}$



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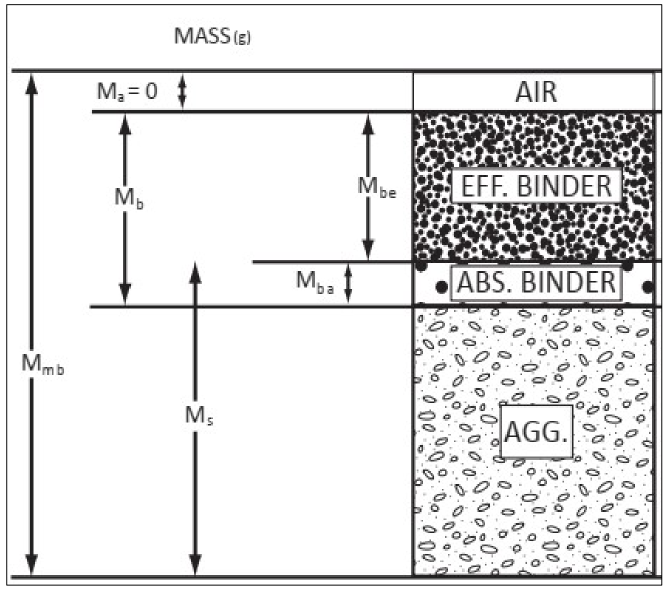
Mixture volumetric parameters

Percent Aggregate P_s

- The total percentage of aggregate in the asphalt mixture
- Expressed as
  - *Percentage of the total mix mass*



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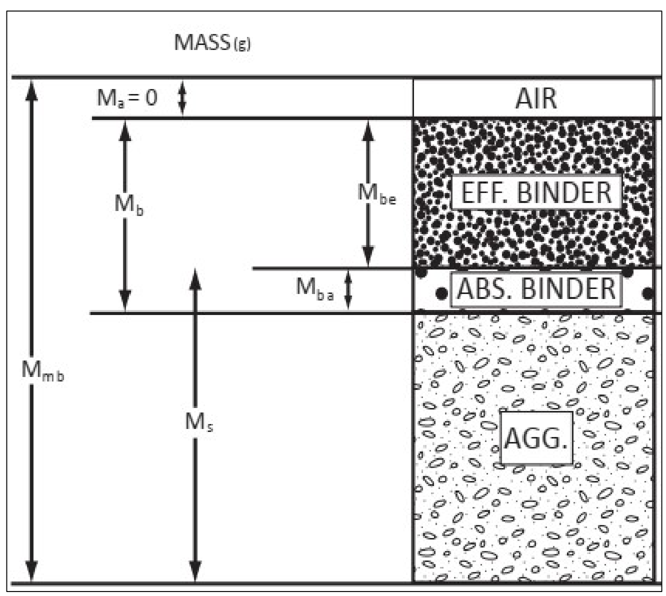
Mixture volumetric parameters

Percent Binder P_b

- The total percentage of asphalt binder in the asphalt mixture
- Expressed as
  - *Percentage of the total mix mass*
  - *Percentage of the aggregate mass*
  - *Note that $P_s + P_b = 100\%$*



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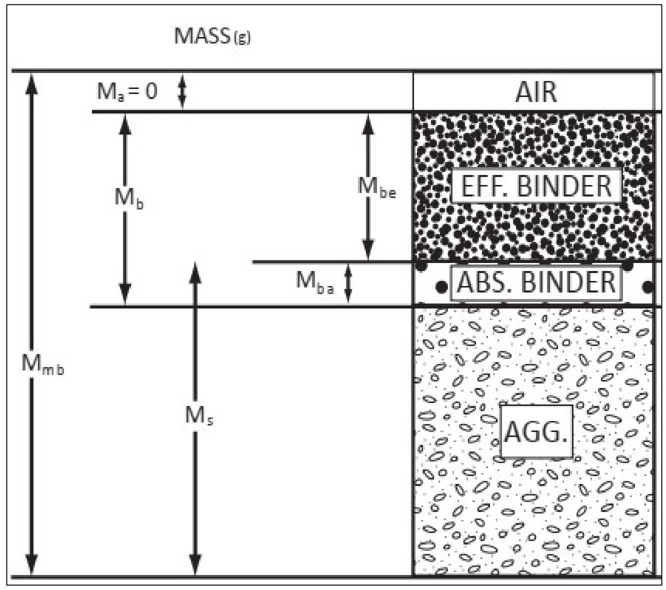
Mixture volumetric parameters

Percent Binder Absorbed (P_{ba}

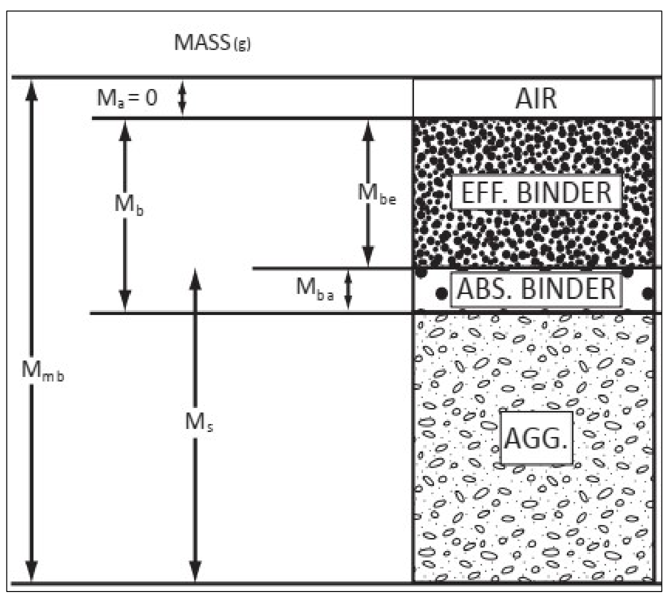
- ❑ The portion of asphalt ***absorbed*** into the aggregate particles.
- ❑ Expressed as
  - ➢*A percentage of the total aggregate mass*
  - ➢$P_{ba} = 100 \times \frac{M_{ba}}{M_s}$
  - ➢$P_{ba} = 100 \times \frac{(Gse - G\quad)}{(Gse \times Gsb)} \times G_b$



Mixture volumetric parameters

Percent Binder Effective P_{be}

- ❑ The functional portion of the asphalt binder that coats the aggregate in the asphalt mixture but is ***not*** absorbed into the aggregate
- ❑ Expressed as
  - ➢*A percentage of the total mix mass*
- ❑ $P_{be} = 100 \times \frac{M_{be}}{M_{mb}}$
- ❑ $P_{be} = P_b - \frac{P_{ba}}{100} \times P_S$



HMA Mix Design

Asphalt Mixtures Volumetric

Volumetric Analysis procedures

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Volumetric analysis Procedures

The measurements needed for Volumetric analysis are:

1. Measure the bulk specific gravities of the coarse aggregate and fine aggregate
   - *(AASHTO T 85 or ASTM C 127) and of the fine aggregate (AASHTO T 84 or ASTM C 128).*
2. 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).*
3. Calculate the bulk specific gravity of the aggregate combination (Blend) in the paving mixture.
4. Measure the maximum specific gravity of the loose paving mixture
   - *(ASTM D 2041 or AASHTO T209).*
5. Measure the bulk specific gravity of the compacted paving mixture
   - *(ASTM D 1188/D 2726 or AASHTO T166).*

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Volumetric analysis Procedures

The calculations needed for Volumetric analysis are:

6. Calculate the effective specific gravity of the aggregate.
7. Calculate the maximum specific gravity at other asphalt contents.
8. Calculate the asphalt absorption of the aggregate.
9. Calculate the effective asphalt content of the paving mixture.
10. Calculate the percent voids in the mineral aggregate (VMA) in the compacted paving mixture.
11. Calculate the percent air voids (AV) in the compacted paving mixture.
12. Calculate the percent voids filled with asphalt (VFA) in the compacted paving mixture

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Example

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Example -

- Calculate all volumetric quantities based on the following laboratory results

Mixture Components

Material	Specific Gravity	Specific Gravity: Bulk	Mix Composition: Percent by Mass of Total Mix	Mix Composition: 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

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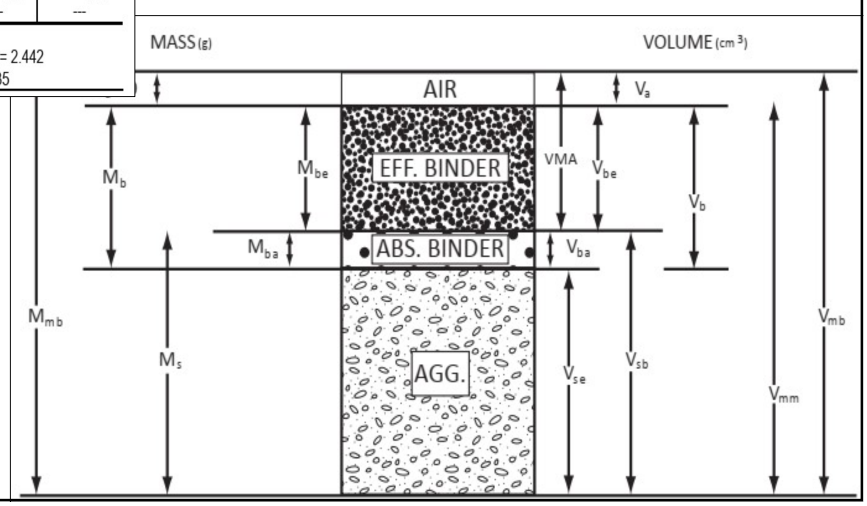
Mixture Components

Material	Specific Gravity	Specific Gravity: Bulk	Mix Composition: Percent by Mass of Total Mix	Mix Composition: 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



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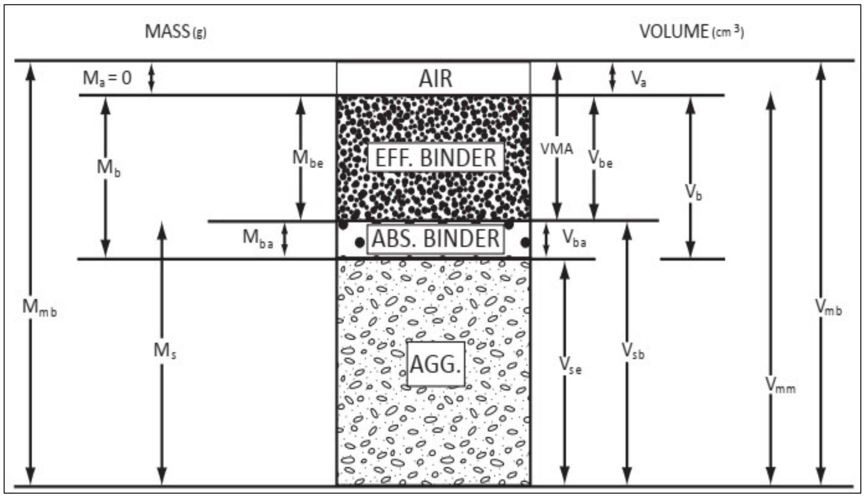

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Solution

Bulk Specific Gravity of Aggregate

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

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

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

Mixture Components

Material	Specific Gravity		Mix Composition	
		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

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Solution

Effective Specific Gravity of Aggregate

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

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				

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

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Solution

Maximum Specific Gravity of Mixtures with Different Asphalt Contents

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

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				

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

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Solution

Asphalt Absorption

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				

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

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

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Solution

Effective Asphalt Content of a 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				

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

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

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Solution

Percent VMA in Compacted 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				

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

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

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Solution

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				

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

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

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Solution

Percent VFA in Compacted Mixture

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

Mixture Components

Material	Specific Gravity		Mix Composition	
		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

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

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HMA Mix Design

Asphalt Mixtures Volumetric

Discussion on volumetric properties

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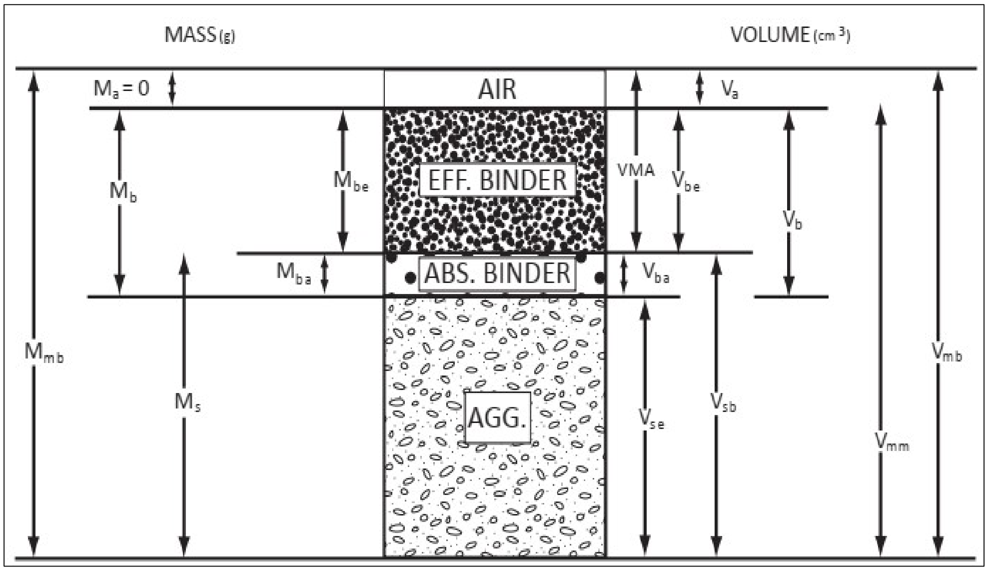
Volumetric analysis

Phase Diagram



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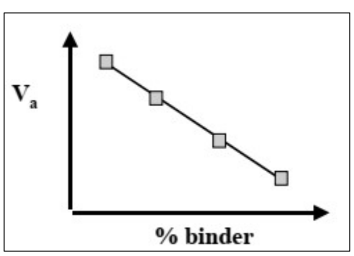
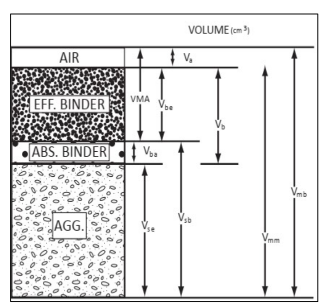
Air voids parameter

Effect of air voids

- It should be emphasized that the design level of air voids (4 percent) is the level desired after several years of traffic.
- This design air void range will normally be achieved in the field if
  - *The mix is designed at the correct compactive effort*
  - *The percent air voids **after construction** is no more than 8 percent.*





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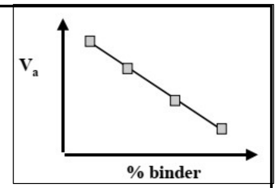
Air voids Parameter

Effect of air voids



- Rutting and shoving are expected to be happened if
  - *Mixtures that ultimately consolidate to less than 2 percent air voids.*
  - *Several factors may contribute to this occurrence,*
    - An arbitrary or accidental increase in asphalt content at the mixing facility
    - an **increased** amount of ultra-fine particles passing the 75-µm (No. 200)sieve, which can act as an asphalt extender
- Premature cracking, raveling and stripping are expected to be happened if :
  - The final air void content of the pavement is above 5 percent
  - or if pavement initially constructed with over 8 percent air voids

Therefore, adjustments of the design asphalt content to less than 0.5 percent air voids from the median of the design criteria (4 percent air voids)

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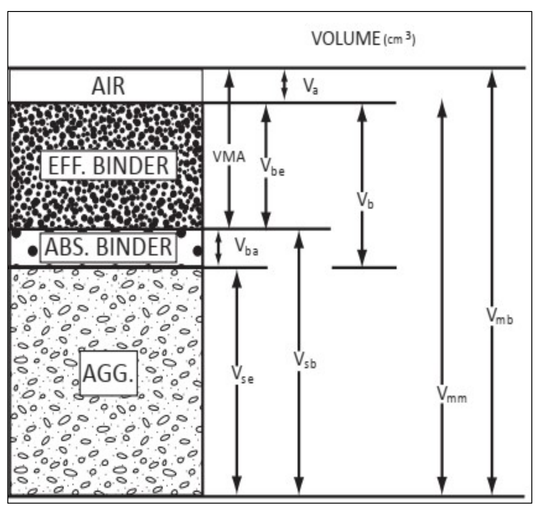
VMA Parameter

- VMA represents the void space between aggregate particles.
- The goal is to furnish enough space for the asphalt binder so it can provide adequate adhesion to bind the aggregates, ***but*** without bleeding when the temperatures rise, and the asphalt expands.
- In many cases, the most difficult mix design property to achieve is a minimum amount of VMA
  - *Therefore, a minimum values for VMA at the design air void content is specified*



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Bleeding

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VMA Parameter

Factors affecting VMA – Minor factors

- **Binder type**
  - *Stiffer binders* whether neat or modified, can increase the resistance to the compaction in the laboratory or in the field
- **Binder quantity**
  - *Asphalt binder will add lubrication to the mix and increase the ability of the aggregate structure to consolidate.*
  - *Small changes in binder content, at or near the design binder content, typically will have minimal effect on the compacted VMA*

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VMA Parameter

Factors affecting VMA – Minor factors

❑ Sample temperature

- As the mixture temperature cools, the overall mixture viscosity will increase. This increasing mixture viscosity will increase the resistance to compaction in the mold and in the field, thus resulting in an increased VMA condition.

❑ Aggregate shape, strength and texture

- More cubical or angular materials will increase the resistance to compaction.
- Rougher surface textures *will increase the resistance to compaction*.
- **Aggregate strength is critical since** a weak aggregate can degrade or break down during compaction, thus changing the gradation and greatly impacting VMA

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VMA Parameter

Factors affecting VMA – Major factors

❑ Type and amount of laboratory compactive effort

- *Intuitively, a higher number of gyrations or number of blows will also decrease the VMA in a compacted specimen*
- *Gyratory compactors utilized in the Superpave system impart significantly more energy into a specimen than traditional impact hammers used in the Marshall method and*
  - Therefore, the Gyratory compactors will result in lower VMA for any given blend of aggregate

❑ Aggregate gradation

- *The gradation of an aggregate blend is perhaps one of the most influential factors governing VMA*

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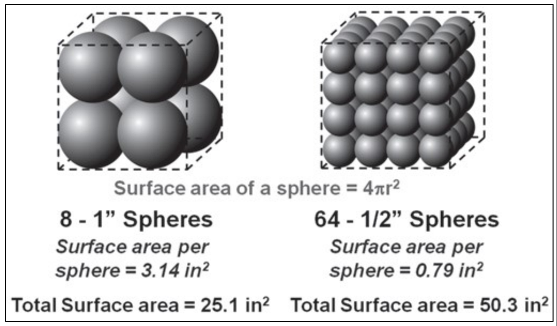
VMA Parameter

Example : Effects of aggregate NMAS on VMA

- As the Nominal Maximum Aggregate Size of the mix decreases, the surface area of the total aggregate structure increases.
  - *Therefore, the percentage of binder necessary to adequately coat the particles increases.*
  - *Since the target air voids (V_a) typically remains the same*
  - *The VMA must increase to allow sufficient room for the additional asphalt binder.*



The specified minimum values for VMA at the design air void content of four percent are a function of nominal maximum aggregate size.

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VMA Parameter

Example : Effects of aggregate NMAS on VMA

The specified minimum values for VMA at the design air void content of four percent are a function of nominal maximum aggregate size.

Nominal Maximum Particle Size[1,2]		Minimum VMA, percent		
		Design Air Voids, Percent[3]		
mm	in.	3.0	4.0	5.0
1.18	No. 16	21.5	22.5	23.5
2.36	No. 8	19.0	20.0	21.0
4.75	No. 4	16.0	17.0	18.0
9.5	⅜	14.0	15.0	16.0
12.5	½	13.0	14.0	15.0
19.0	¾	12.0	13.0	14.0
25.0	1.0	11.0	12.0	13.0
37.5	1.5	10.0	11.0	12.0
50	2.0	9.5	10.5	11.5
63	2.5	9.0	10.0	11.0

NOTES:
1. Standard Specification for Wire Cloth Sieves for Testing Purposes, ASTM E11 (AASHTO M 92)
2. The nominal maximum particle size is one size larger than the first sieve to retain more than 10 percent.
3. Interpolate minimum voids in the mineral aggregate (VMA) for design air void values between those listed.

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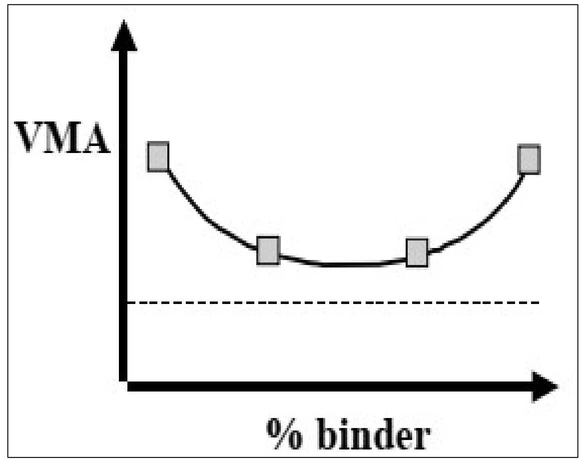
VMA Parameter

Evaluation of VMA curve with binder content

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

- Normally, the curve exhibits a flattened U-shape,
  - *Decreasing to a minimum value and then increasing with increasing asphalt content*
- In reality, the total volume changes across the range of asphalt contents
  - *The assumption of a constant unit volume is not accurate.*



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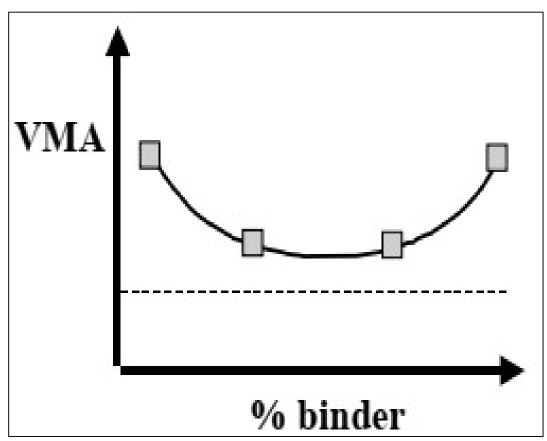
VMA Parameter

Evaluation of VMA curve with binder content

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

- With the increase in asphalt, the mix actually becomes more workable and compacts more easily, meaning more weight can be compressed into the unit volume.
  - *Therefore, up to a point, the bulk density of the mix increases and the VMA decreases*
- **<u>At some point</u>** as the asphalt content increases (the bottom of the U-shaped curve), the VMA begins to increase
  - *because relatively higher specific gravity material (aggregate) is **displaced** and pushed apart by the lower specific gravity material (asphalt cement).*



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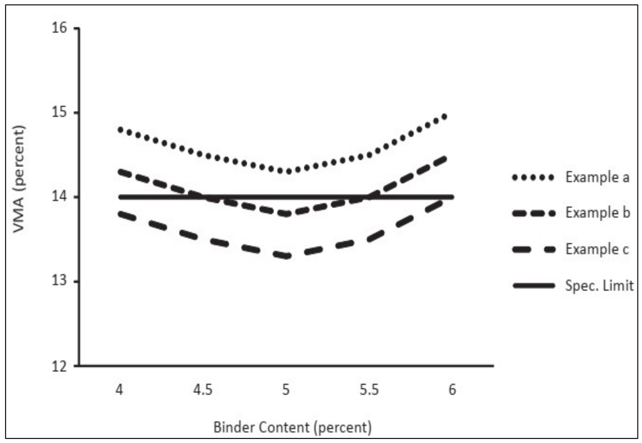
VMA Parameter

Evaluation of VMA curve with binder content

- If the bottom of the U-shaped VMA curve is very flat,
  - *This mean that the compacted mixture is not as sensitive to asphalt content in this range as some other factors.*
  - *In the normal range of asphalt contents, compactability is influenced more by aggregate properties.*
- IF the bottom of the U-shaped VMA curve falls below the minimum criteria level
  - *This is an indication that changes to the job-mix formula are necessary*



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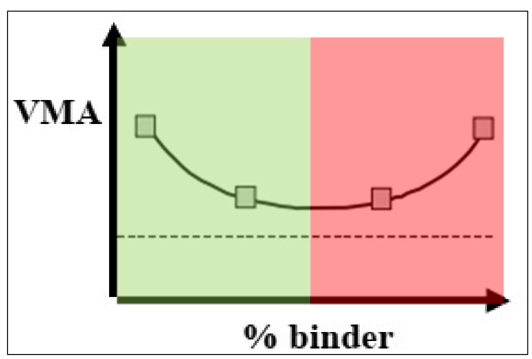
VMA Parameter

Evaluation of VMA curve with binder content

- It is recommended to **avoid** asphalt contents on the “wet,” or righthand,
  - Design asphalt contents in this range have a tendency to bleed and/or exhibit plastic flow when placed in the field
- Ideally, **the design asphalt content** should be selected slightly to the left of the lowest point of the VMA curve



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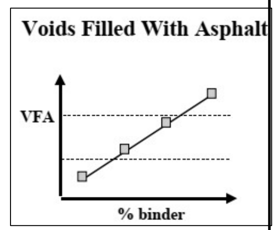
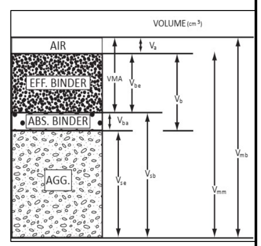
Voids Filled with Asphalt (VFA) Parameter

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

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

- The main effect of the VFA criteria is to
  - *Limit maximum levels of VMA*
  - *Prevent the design of mixes with marginally acceptable VMA*
  - *Limit maximum levels of asphalt content.*
  - *Restricts the allowable air void content for mixes that are near the minimum VMA criteria*
  - Provide an additional factor of safety in the design and construction process in terms of performance.
    - Since changes can occur between the design stage and actual construction , an increased margin for safety is desirable
- **Usually, factor effects the VMA will affect the VFA**





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Voids Filled with Asphalt (VFA) Param

Marshall Method Criteria[1]	Light Traffic[3] Surface & Base		Medium Traffic[3] Surface & Base		Heavy Traffic[3] Surface & Base	
	Min	Max	Min	Max	Min	Max
Compaction, number of blows each end of specimen	35		50		75	
Stability[2], N (lb.)	3336 (750)	-	5338 (1200)	-	8006 (1800)	-
Flow[2,4,5], 0.25 mm (0.01 in.)	8	18	8	16	8	14
Percent Air Voids[7]	3	5	3	5	3	5
Percent Voids in Mineral Aggregate (VMA)[6]	See Table 7.3					
Percent Voids Filled With Asphalt (VFA)	70	80	65	78	65	75

Nominal Maximum Particle Size[1,2]		Minimum VMA, percent		
		Design Air Voids, Percent[3]		
mm	in.	3.0	4.0	5.0
1.18	No. 16	21.5	22.5	23.5
2.36	No. 8	19.0	20.0	21.0
4.75	No. 4	16.0	17.0	18.0
9.5	3/8	14.0	15.0	16.0
12.5	1/2	13.0	14.0	15.0
19.0	3/4	12.0	13.0	14.0
25.0	1.0	11.0	12.0	13.0
37.5	1.5	10.0	11.0	12.0
50	2.0	9.5	10.5	11.5
63	2.5	9.0	10.0	11.0

NOTES:
1. Standard Specification for Wire Cloth Sieves for Testing Purposes, ASTM E11 (AASHTO M 92)
2. The nominal maximum particle size is one size larger than the first sieve to retain more than 10 percent.
3. Interpolate minimum voids in the mineral aggregate (VMA) for design air void values between those listed.

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Dust to binder ratio (Dust Proportion) Parameter

Definition

- The dust to binder ratio is ***the ratio*** of the percentage of aggregate passing the 0.075-mm (No. 200) sieve($P_{0.075}$) to the effective binder (P_{be}).

  - *Dust ratio = $P_{0.075}/P_{be}$*

- This property addresses the workability of asphalt mixtures.

  - *A low $P_{0.075}/P_{be}$ often results in a tender mix,*
    - Tender mix lacks cohesion and is difficult to compact in the field because it tends to move laterally under the roller.
    - Mixes tend to stiffen as the $P_{0.075}$ increases, but too much will also result in a tender mix
  - *A mix with a high $P_{0.075}/P_{be}$ will often exhibit a multitude of small stress cracks during the compaction process (lack sufficient durability), called check-cracking*

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Dust to binder ratio (Dust Proportion) Parameter

Criteria

- The typical allowable range for this property is 0.6 – 1.2, with the following exceptions:

  - *For 4.75-mm mixes, the allowable range is 0.9 – 2.0*
  - *For coarse-graded mixes whose gradation plots below the Primary Control Sieve (PCS) on a 0.45 power chart,*
    - The allowable range may be increased to 0.8–1.6.

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Jordanian National Building council

Specifications for highway and bridge construction

Table 4.15: JOB MIX REQURIEMENTS TO BITUMINOUS BINDER AND WEARING COURSES

Property	Heavy Traffic		Medium-Light Traffic	
	Binder	Wearing	Binder	Wearing
Marshall Stability at 60°C (kg)	900	1000	800	900
Flow (mms)	2 - 3.5	2 - 3.5	2 - 4	2 - 4
Voids in Mineral Aggregate (VMA)	13 (-1)	14 (-1)	13 (-1)	14 (-1)
Air Voids (%)	4 - 7	4 - 6	3 - 5	3 - 5
Stiffness (Kg/mm)	500 (Min)	500 (Min)	400 (Min)	400 (Min)
* Loss of stability (%)	25 (max)	25 (max)	25 (max)	25 (max)

Table 4.14: JOB MIX REQUIREMENTS FOR BITUMINOUS BASE COURSE

Property	Heavy Traffic	Medium-Light Traffic
Marshall Stability at 60°C (Kg)	750	700
Flow (mm)	2 - 3.5	2 - 4
Voids in Mineral Aggregate (VMA)	12(min)	12(min)
Air Voids (%)	4 - 8	4 - 7
Filler Bit Ratio	1.2 - 1.5	1.0 - 1.4
Stiffness (Kg/mm)	300(min)	250(min)
*Loss of Stability (%)	25 (Max)	25 (Max)

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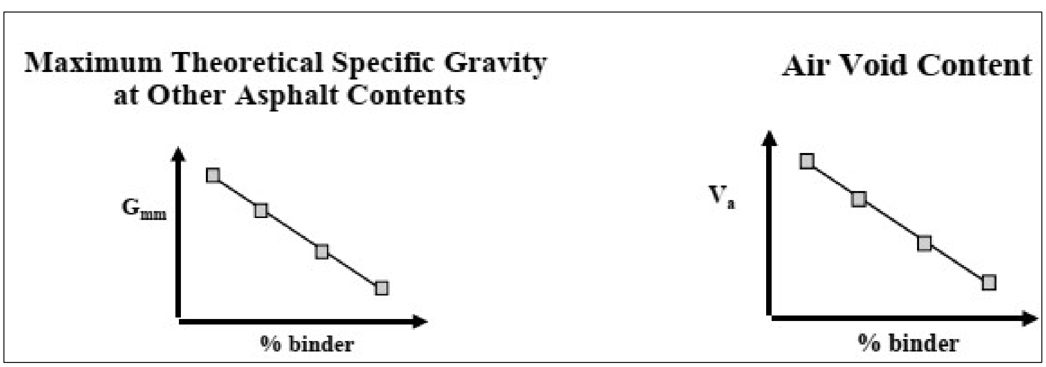
Effect of Changing Asphalt Content on Volumetric Properties



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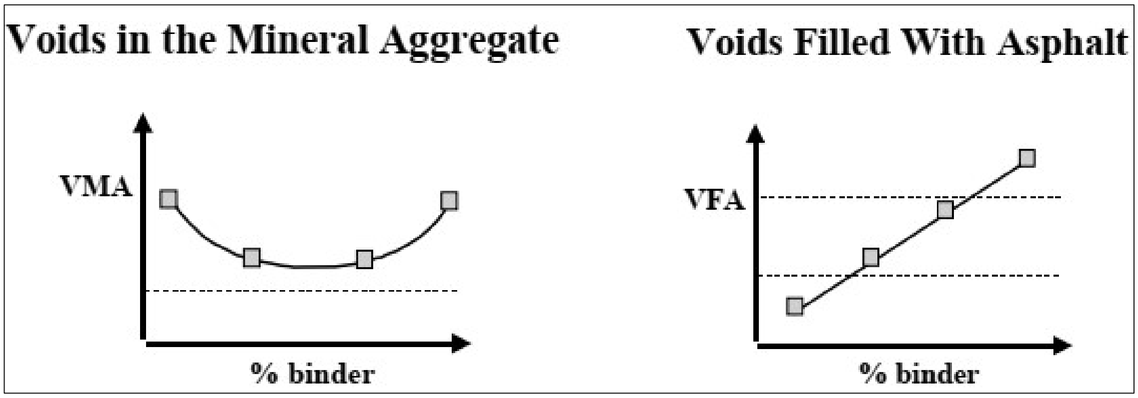
Effect of Changing Asphalt Content on Volumetric Properties



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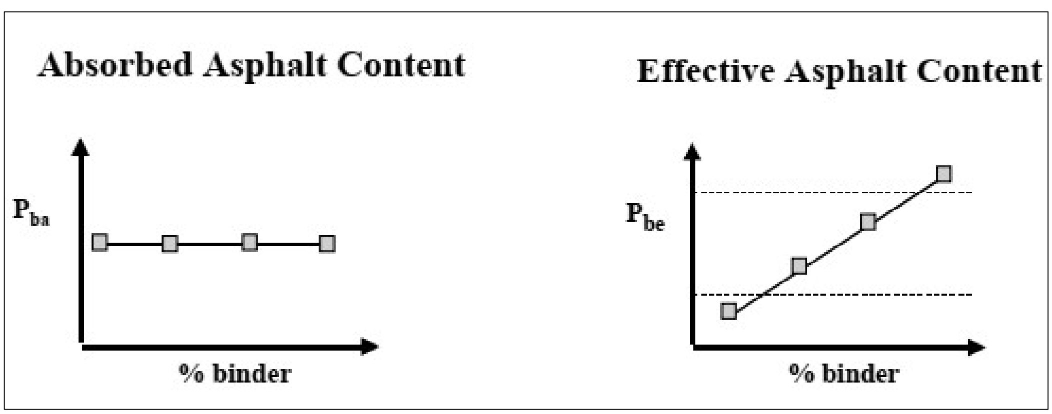
Effect of Changing Asphalt Content on Volumetric Properties



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