# An Introduction to Asphalt Mixture Volumetrics

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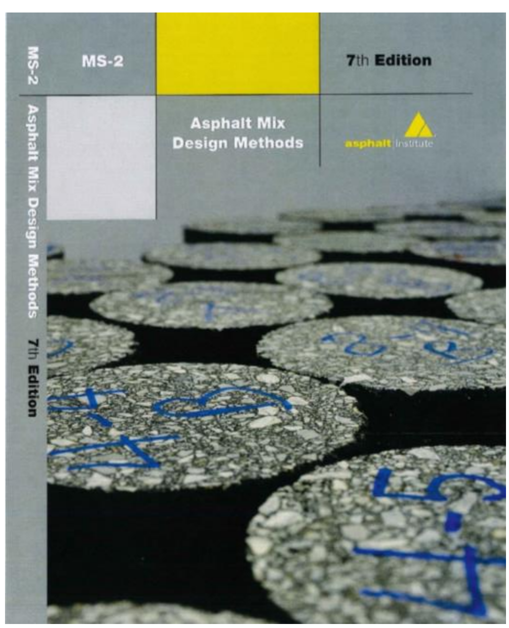
## Presentation is Based on MS-2

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## Mix Design Flowchart

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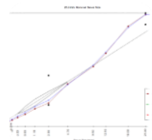
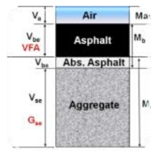
Proceed with all materials

Choose an aggregate blend

Choose optimum % asphalt binder






**Materials selection**
- Aggregates
  - Quality
  - Gradation or size
- Asphalt binder type
- Additives

**Design aggregate structure trial blend design**
- Target 4% air voids for all designs
- Which aggregate blend is best for you?
- Based on spec, economics

**Conduct in-depth volumetric mix design**
- How does my mixture respond to various amounts of asphalt binder?

**Test for stripping or moisture damage or performance testing**

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## Obtaining the Right Balance

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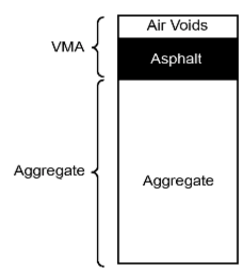
# Achieved through

- Volumetric Analysis of the Mixture
- Future Performance testing

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## Intent of Laboratory Compaction?

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To simulate the in-place density of HMA after it has endured several years of traffic

**In-place density** | **Future traffic** | **Design density**


Air Voids

15 - 25% Before Rolling

6 - 9% After Rolling

Air Voids

3 - 5% Marshall

4% Superpave

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## What Compactor Simulates Compaction Best?

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- SHRP research identified the best practical compactor - Superpave Gyratory compactor
- SGC better than Marshall or Hveem

MS-2
Pg. 39 – 4.3

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## Gyratory Compactors

Pine

Troxler

Cooper / Cox

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## Materials Selection

- Aggregate
- Makes up 93 to 96% of the mixture weight
- Acts as the skeleton of the pavement mixture
  - Skid resistance
  - Stability
  - Workability

- Asphalt Binder
- Makes up 4 to 7% of the mixture weight
- Acts as the “glue” or “muscle” of the mix
  - Flexibility
  - Durability

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## Volumetrics

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- All matter has mass and occupies space
- Volumetrics are the relationships between mass and volume
- Marshall and Superpave mix design based on aggregate and mixture volumetrics

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## Volumetric Analysis Definition

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**The measurement or calculation of the relative masses and volumes occupied by the aggregate, asphalt binder, and air voids in a compacted asphalt mixture**

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## History of Mix Design

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**1890**
- **Barber Asphalt Paving Company**
- Asphalt cement 12 to 15% / Sand 70 to 83% / Pulverized carbonite of lime 5 to 15%

**1905**
- **Clifford Richardson, New York Testing Company**
- Surface sand mix: 100% passing No. 10, 15% passing No. 200, 9 to 14% asphalt
- Asphaltic concrete for lower layers, VMA terminology used, 2.2% more VMA than current day mixes or ~0.9% higher binder content

**1920s**
- **Hubbard Field Method** (Charles Hubbard and Frederick Field)
- Sand asphalt design
- 30 blow, 6" diameter **with compression test (performance)** asphaltic concrete design (Modified HF Method)

Stability

**1927**
- **Francis Hveem** (Caltrans)
- Surface area factors used to determine binder content; **Hveem stabilometer and cohesionmeter** used
- Air voids not used initially, mixes generally drier relative to others, fatigue cracking an issue

Stability + Durability

**1943**
- **Bruce Marshall**, Mississippi Highway Department
- Refined Hubbard Field method, standard compaction energy with drop hammer
- Initially, only used air voids and VFA, VMA added in 1962; **stability and flow utilized**

Stability + Durability

**1993**
- **Superpave**
- Level 1 (volumetric)
- Level 2 and 3 (performance based, but **never implemented**)

BINDER CONTENT LOWER

http://asphaltmagazine.com/history-of-asphalt-mix-design-in-north-america-part-2/

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## Nomenclature for Specific Gravity

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- $G_{xy}$ - Where G equals specific gravity; unit-less
  - x - Designates material
  - y - Designates type of specific gravity
- For (x):
  - s - Aggregate
  - m- Mixture
  - b - Binder
- For (y):
  - m- Maximum
  - a - Apparent
  - b - Bulk
  - e - Effective

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## Aggregate Properties

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***Specific Gravity (G)**- "a dimensionless number defined as the ratio of the density of a material to the density of water."*

$$G = \frac{\frac{m}{v}}{\rho} \quad \text{- or -} \quad \frac{m}{v \times \rho}$$

where:

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

Water is really 0.997g/cc at 25C, but many use 1.000

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## Aggregate Specific Gravities

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- $G_{sb}$ - largest volume, lowest value
- $G_{se}$ - in-between volume, middle value
- $G_{sa}$ - smallest volume, highest value

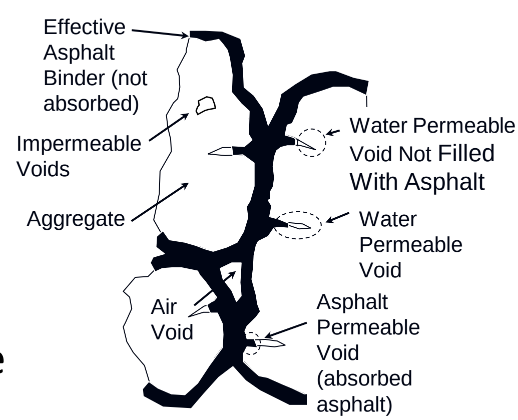


Figure 5.2 **Representation of Microscopic View of Aggregate, Asphalt, and Air Mixture**

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## Coarse Aggregate Specific Gravity

- AASHTO T 85
  - Apparent
  - SSD
  - Bulk
  - Absorption

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**Pg. 48 – 5.3.1**

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## Fine Agg. Specific Gravity (Cone Test)

- AASHTO T 84

Too Wet

Saturated Surface Dry (SSD)

**MS-2**
**Pg. 48 – 5.3.2**

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## Determine Aggregate Specific Gravities

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### What is Specific Gravity?

- It is the ratio between the density of anything compared to the density of water at a standard temperature

$$G = \frac{\frac{M_x}{V_x}}{\frac{M_{H_2O}}{V_{H_2O}}} \quad \frac{M_{H_2O}}{V_{H_2O}} = 1.000 \text{ gram / cm}^3$$

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Pg. 45 – 5.1

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## Specific Gravity is the Bridge Between Volume and Mass

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**Volume**

$$V = \frac{M}{G}$$

$$\boldsymbol{G = \frac{M}{V}}$$

**Mass**

$$M = V \times G$$

**In the metric system...**
*the magnitudes of specific gravity (no units) and unit weight (g/cc) are always the same because water weighs 1 g/cc*

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## Specific Gravity

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- Relates Volume to Mass

mass of object

$$V = \frac{M}{G \times 1.000}$$

volume of object

specific gravity of object

density of water

*Specifically, density is 0.997 at 25.0℃*

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## Specific Gravity

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- Relates Mass to Volume

volume of object

$$\boldsymbol{M = V \times G \times 1.000}$$

mass of object

specific gravity of object

density of water at room temperature

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## Specific Gravities

- The specific gravity of three different materials are obtained and used in volumetric analysis
  - Aggregate ($G_{sb}$) – *furnished by designer or producer*
  - Asphalt ($G_b$) – *furnished by the supplier*
  - Mixture ($G_{mb}$) – *cannot be determined until mixture testing is completed*

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## Aggregate Specific Gravity

- Mineral aggregate is porous.
- The amounts of water and asphalt absorption differ
  - asphalt absorption is typically 30 – 80% of water absorption
- Three different specific gravities are needed to account for these variations.
  - $G_{sa}$ = Apparent Specific Gravity
  - $G_{se}$ = Effective Specific Gravity
  - $G_{sb}$ = Bulk Specific Gravity

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## 3 Different Aggregate Specific Gravities

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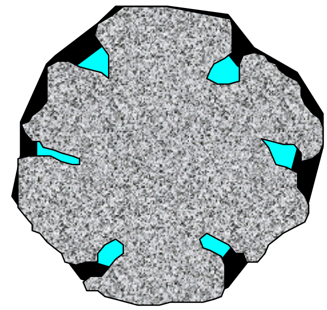
- Apparent ($G_{sa}$) Volume
  - excludes absorbed water volume
- Effective ($G_{se}$) Volume
  - excludes absorbed asphalt volume
  - Must use mixture testing to determine $G_{sa}$ Volume. ($G_{mm}$)
- Bulk ($G_{sb}$) Volume

Same Mass



Different Volumes

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Pg. 47 – 5.2.2

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## Aggregate Bulk Specific Gravity

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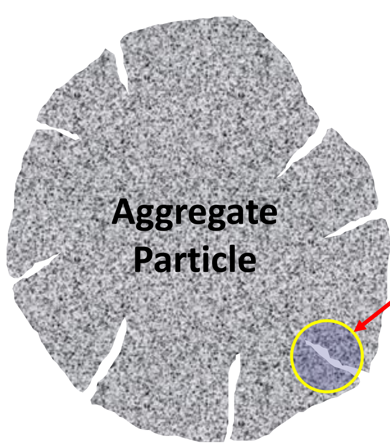
"SSD" Level




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

- **Bulk Volume** = solid volume + water permeable pore volume

- *Uses Saturated Surface Dry (SSD) condition. The aggregate is Saturated but the Surface is Dry*

*This is a measured specific gravity*

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## Aggregate Effective Specific Gravity

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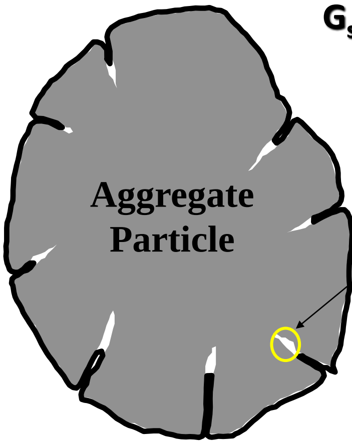
$$G_{se} = \frac{\text{Dry Mass}}{\text{Eff Vol}} \Big/ 1.000 \text{ g/cm}^3$$




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

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## Aggregate Apparent Specific Gravity

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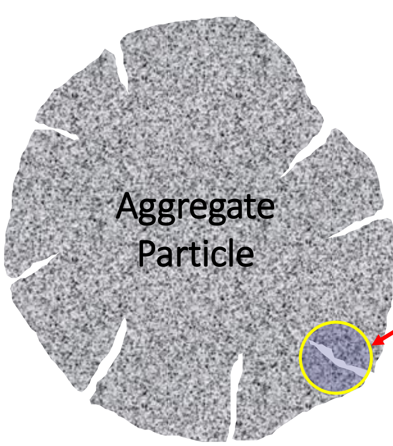
$$G_{sa} = \frac{Dry\ Mass}{App\ Vol.} \div 1.000\ g/cm^3$$

- **Apparent Volume** = volume of solid aggregate particle only *(Bulk Vol. – Abs $H_2O$ Vol.)*




*not included*

*This is a measured specific gravity*

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## Combined $G_{sb}$ & $G_{sa}$ for Each Stockpile

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- Laboratory testing is performed individually on the coarse and fine fractions of the stockpile.
- These values must be combined into one value for each stockpile.

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## HMA Volumetric Terms

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- Air voids of mix, $P_a$
- Voids in mineral aggregate, VMA
- Bulk specific gravity of mix, $G_{mb}$
- Maximum specific gravity of mix, $G_{mm}$
- Voids filled with asphalt, VFA
- Bulk specific gravity of aggregate, $G_{sb}$
- Effective specific gravity of aggregate, $G_{se}$
- Dust Proportion, DP

MS-2
Pg. 46 – 5.2

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## Importance of Air Voids

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- Field performance has shown that typical mixtures designed with low air voids (maybe < 2%) are susceptible to rutting and shoving
- Mixtures designed over about 5% air voids are susceptible to raveling, oxidation and a general lack of durability
- 4% air void design is an empirically derived target that allows for thermal expansion of the binder along with a cushion for future compaction

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## Air Voids

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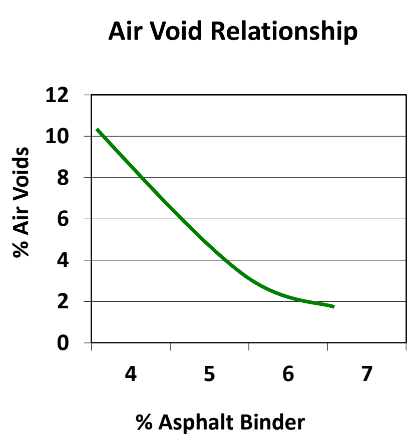


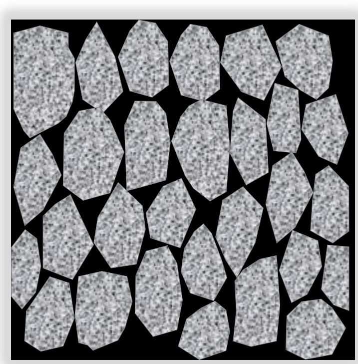

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## VMA: Voids in Mineral Aggregate

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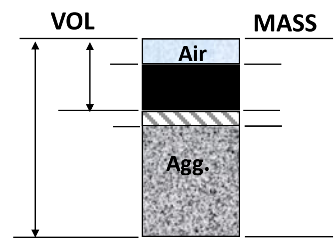
- Definition
  - Volume of *inter-granular* void space in a compacted mix
- % by volume total mix
- *Does not* include volume of absorbed asphalt




*Which aggregate gravity is used to calculate the VMA of the mixture?*

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Pg. 54 – 5.6

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## VMA Equation

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

Where:
VMA = Voids in the Mineral Aggregate
$G_{mb}$ = bulk specific gravity of the mix
$P_s$ = Percent aggregate in the specimen
$G_{sb}$ = bulk specific gravity of the aggregate blend

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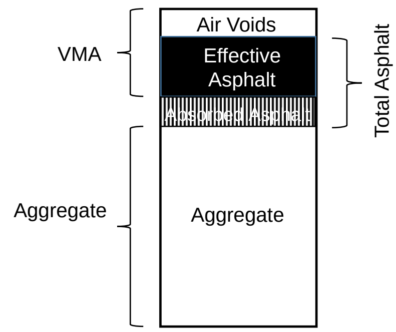
## Importance of VMA

- VMA is the volume of the voids in a compacted aggregate sample to accommodate effective asphalt and air.
  - Assure sufficient binder coating
  - Maintain 4% Air voids

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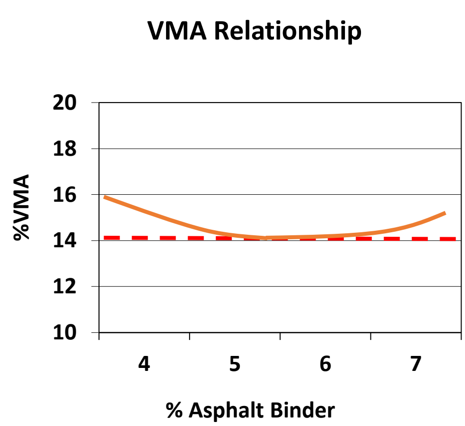
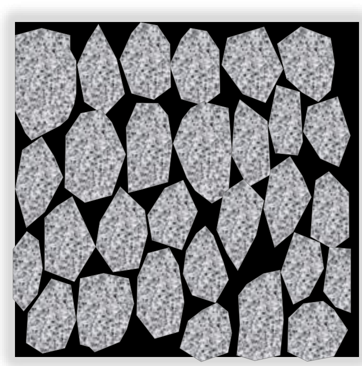
## VMA and %AC



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## High VMA Mixes

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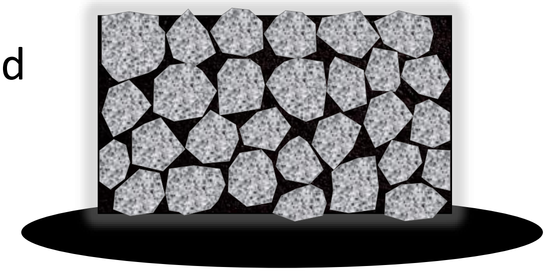
SMA and OGFC are specialty mixes that are designed with very high VMA and are engineered to minimize drain down



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## Voids Filled with Asphalt (VFA)

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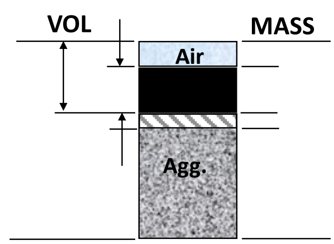
- Definition
  - Percentage of VMA filled with asphalt
- Similar to degree of saturation in soils
- Limits excessive VMA




MS-2
Pg. 56 – 5.7

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## VFA Equation

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$$VFA = 100 \times \frac{(VMA - P_a)}{VMA}$$

Where:
VFA = Percent volume of VMA filled with asphalt
VMA = Percent Voids in the Mineral Aggregate
$P_a$ = Percent Air Voids of the Total mix volume

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## Dust Proportion

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- Dust = % Passing the .075mm sieve
- Previously referred to as the Dust / Asphalt ratio
- A parameter that measures the mixture "mastic"

MS-2
Pg. 57 – 5.10

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## Dust Proportion

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- Originally established using the total asphalt content
- $P_{be}$ is now recommended
- Usage of $P_b$ or $P_{be}$ varies in different regions – Check the specifications.
- Recommended Criteria
  - 0.6 – 1.2
  - 0.8 – 1.6 for extra coarse mixtures

$$DP = \frac{P_{0.075}}{P_{be}}$$





## Phase Diagram

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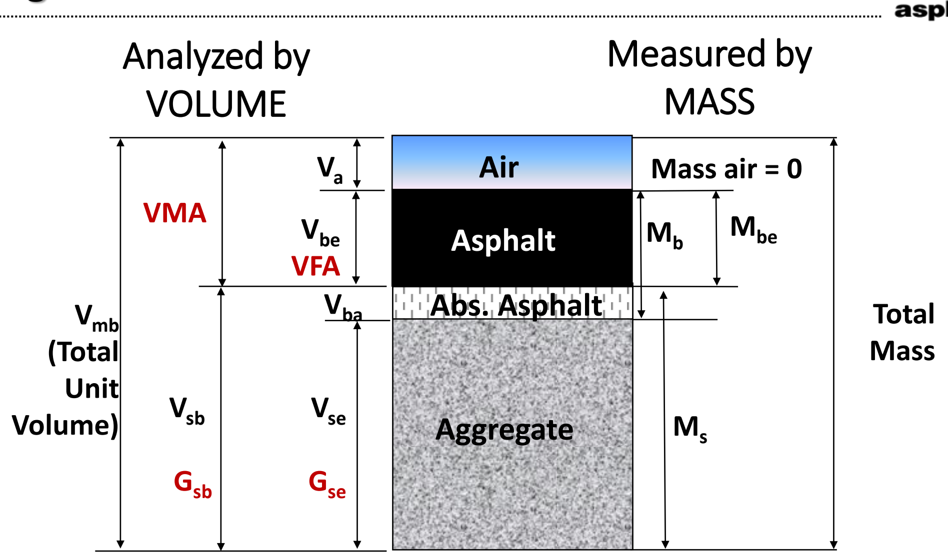
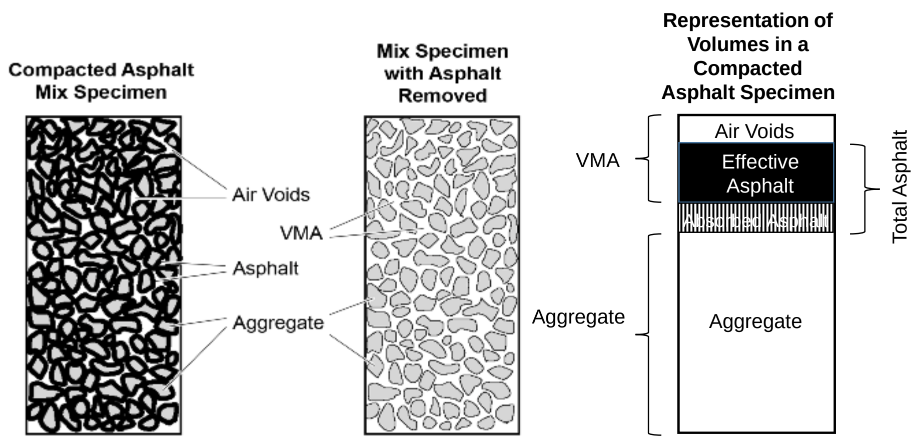



*Specific Gravity bridges the gap*

$V_{binder} = V_{be} + V_{ba}$

See MS-2
Pg. 48 – 5.3

## Importance of Volumetric Properties




MS-2
Pg. 13 – Figure 2.7

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## Many Elements Affect Volumetric Properties

- Binder quantity & binder properties
  - Stiffness
  - Modification
  - Temperature
- Aggregate characteristics
  - Gradation
  - Particle shape
  - Surface texture
  - Hardness
  - Absorption

Every mixture can be different!

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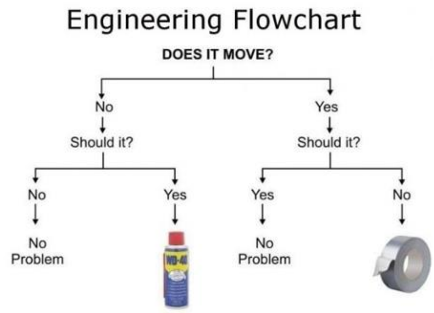
## Final Thoughts on Mix Design

- Key Points to Keep in Mind
  1. **"Use What Works"**
  2. **"Eliminate What Doesn't"**
  3. **"Be as Simple as Possible, Be Practical, and Be Correct"**





**"Good doesn't have to be complicated and complicated isn't always good!"**

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## Questions?

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