An Introduction to Asphalt Mixture Volumetrics

Idaho Asphalt Conference
October 28, 2021
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Presentation is Based on MS-2
Mix Design Flowchart

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

Obtaining the Right Balance

Achieved through
- Volumetric Analysis of the Mixture
- Future Performance testing
**Intent of Laboratory Compaction?**

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

- **In-place density**
  - Air Voids: 15 - 25% Before Rolling
  - Air Voids: 6 - 9% After Rolling

- **Future traffic**

- **Design density**
  - Air Voids: 3 - 5% Marshall
  - Air Voids: 4% Superpave

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**What Compactor Simulates Compaction Best?**

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

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
Volumetrics

- 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

Volumetric Analysis Definition

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

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
  • 10 blow, 6" diameter with compression test (performance) asphaltic concrete design (Modified HF Method)

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

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

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


Nomenclature for Specific Gravity

G<sub>xy</sub> - 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
Aggregate Properties

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

\[
G = \frac{m}{v \rho} \quad \text{or} \quad \frac{m}{v x \rho}
\]

where:
- \(G\) = specific gravity
- \(m\) = mass of the material
- \(v\) = volume of the material
- \(\rho\) = density of water

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

Aggregate Specific Gravities

- \(G_{sb}\) - 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
Coarse Aggregate Specific Gravity

• AASHTO T 85
  ◦ Apparent
  ◦ SSD
  ◦ Bulk
  ◦ Absorption

Fine Agg. Specific Gravity (Cone Test)

• AASHTO T 84

Too Wet

Saturated Surface Dry (SSD)
Determine Aggregate Specific Gravities

What is Specific Gravity?

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

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

Specific Gravity is the Bridge Between Volume and Mass

Volume

\[
V = \frac{M}{G}
\]

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
Specific Gravity

• Relates Volume to Mass

\[ V = \frac{M}{G \times 1.000} \]

Specifically, density is 0.997 at 25.0 °C

Specific Gravity

• Relates Mass to Volume

\[ M = V \times G \times 1.000 \]
**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
3 Different Aggregate Specific Gravities

• 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

Aggregate Bulk Specific Gravity

"SSD" Level

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

• 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
Aggregate Effective Specific Gravity

\[ G_{se} = \frac{\text{Dry Mass}}{\text{Eff Vol}} \div 1.000 \text{ g/cm}^3 \]

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

Aggregate Particle

Aggregate Apparent Specific Gravity

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

- Apparent Volume = volume of solid aggregate particle only
  (Bulk Vol. – Abs H2O Vol.)

Aggregate Particle

This is a measured specific gravity
**Combined $G_{sb} & G_{sa}$ for Each Stockpile**

- 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.

**HMA Volumetric Terms**

- 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
Importance of Air Voids

• 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

Air Voids

Air Void Relationship

% Air Voids

% Asphalt Binder

12/29/2021
VMA: Voids in Mineral Aggregate

- 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?*

**VMA Equation**

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

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
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

VMA and %AC

![VMA Relationship Graph]

- [Graph showing the relationship between VMA and % Asphalt Binder]
High VMA Mixes

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

Voids Filled with Asphalt (VFA)

• Definition
  ◦ Percentage of VMA filled with asphalt

• Similar to degree of saturation in soils

• Limits excessive VMA
VFA Equation

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

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

Dust Proportion

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

- 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**

- Analyzed by VOLUME
- Measured by MASS

$V_{mb}$ (Total Unit Volume)

Specific Gravity bridges the gap

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

See MS-2
Pg. 48 – 5.3
Importance of Volumetric Properties

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!
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!"

Thank You Asphalt Institute Membership
Questions?