Back to Basics - Volumetrics

WAPA
WISCONSIN ASPHALT PAVEMENT ASSOCIATION

November 28, 2017

Paul Eggen, P.G.

OMNI ASSOCIATES

Informed by and "borrowing" from. . .

Back 2 Basics: Volumetrics

Understanding How They Control Performance

April 4, 2017

NAPA webinars

Gerry Huber
Heritage Research Group

"I learn something new every day. The problem is, most of it is stuff that I probably should already know."

Unknown

History of Mix Design & Volumetrics

1905
- Clifford Richardson - New York Testing Co.
- Calculates VMA and adjusts for correct %AC

1920's
- Hubbard Field Method - Asphalt Association
- Used lab compacted specimens and volumetric analysis.

1932
- Hveem Design Method - California
- Determined Asphalt content based on aggregate surface area (film thickness)

History of Asphalt Mix in North America – Asphalt Magazine

History of Mix Design & Volumetrics

1930's

- Marshall Mix Design - Mississippi
- Used Voids and VFA

1962

- Asphalt Institute updates MS-2
- Incorporates VMA into Marshall Design
- VMA requirements based on NMAS

History of Asphalt Mix in North America – Asphalt Magazine

Rutting in the 1980s eventually led to Superpave

History of Mix Design & Volumetrics

1993

- SuperPave Volumetric Mix Design – SHRP
- Gyratory Compactor, VMA used to determine minimum %AC
- Consensus aggregate properties on blend.

2000

- WisDOT adopts Superpave mix design methodology

History of Asphalt Mix in North America – Asphalt Magazine

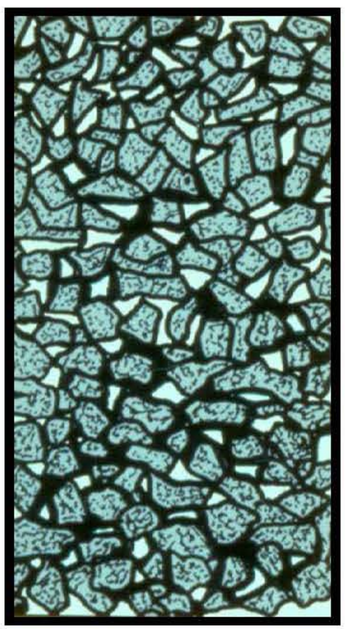
ASPHTEC-1, January 1992

Terminology

- **Volumetric** – Of or relating to measurement by volume.
- **Gravimetric** – Of or relating to measurement by weight.
- **Empirical** – Based on observation or experience rather than logic or theory (measured).

Superpave Empirical Properties

* Aggregates



* Compacted Mix

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Terminology: Specific Gravity

- Relates Density of an Object to the same Volume of Water

$$D = G \times 1.000$$

Density in g/cm^3

specific gravity of object

density of water

The "Rosetta Stone" for asphalt mix volumetrics

Terminology: Specific Gravity

- Specific Gravity Terms **"G"**
  - G_{mb} - bulk specific gravity of the compacted mix. (Gyratory Puck or Pavement Core)
  - G_b - specific gravity of the binder (~1.03)

Teminology: Specific Gravity

- Specific Gravity Terms **"G"**
  - G_{mm} - theoretical maximum specific gravity of the mix. Uncompacted, no air voids. (Rice test)

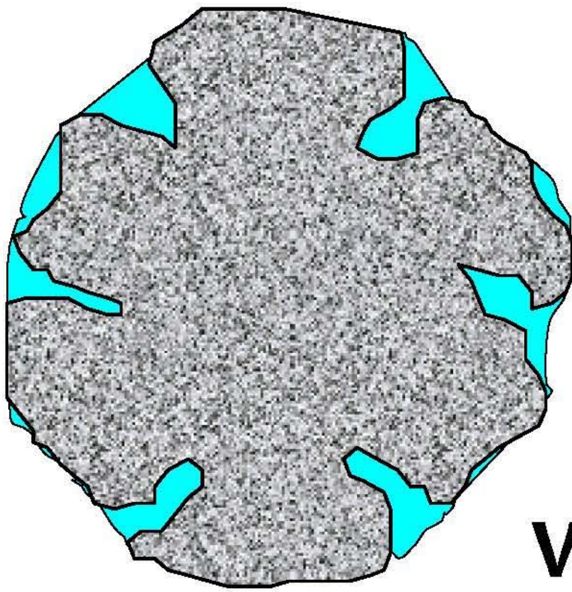
Terminology: Specific Gravity

- Specific Gravity Terms **"G"**
  - G_{mb} - bulk specific gravity of the compacted mix. (Gyratory Puck or Pavement Core)

Terminology: Specific Gravity

- Specific Gravity Terms **"G"**
  - G_b - specific gravity of the binder (~1.03)
  - G_{sb} - bulk specific gravity of the aggregate
  - G_{se} - effective specific gravity of the aggregate

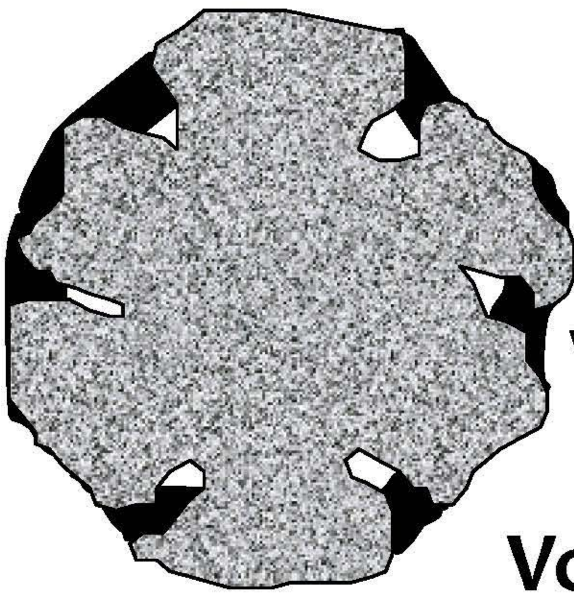
Volume for Bulk Gravity



Gray + Blue area

Volume of the aggregate plus Volume of voids penetrated by water

Volume for Effective Gravity



Gray + White area

Volume of the aggregate
plus
Volume of voids penetrated by water but not by asphalt

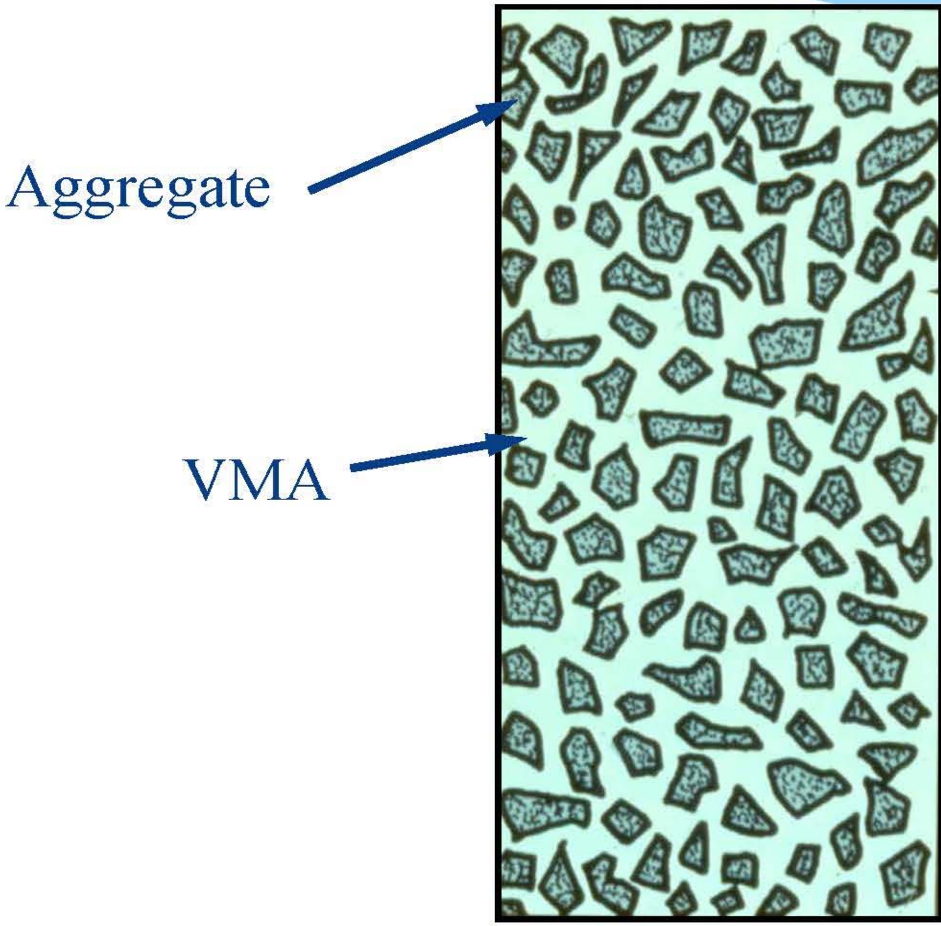
Terminology

- **Air voids (V_a)** – Total *volume* of air in a compacted mix. (3%-4%)
- $V_a = 100 \times (G_{mm} - G_{mb})/G_{mm}$
- Low voids – potential for rutting
- High voids – lower compaction and loss of durability
- *Voids are a big deal!*

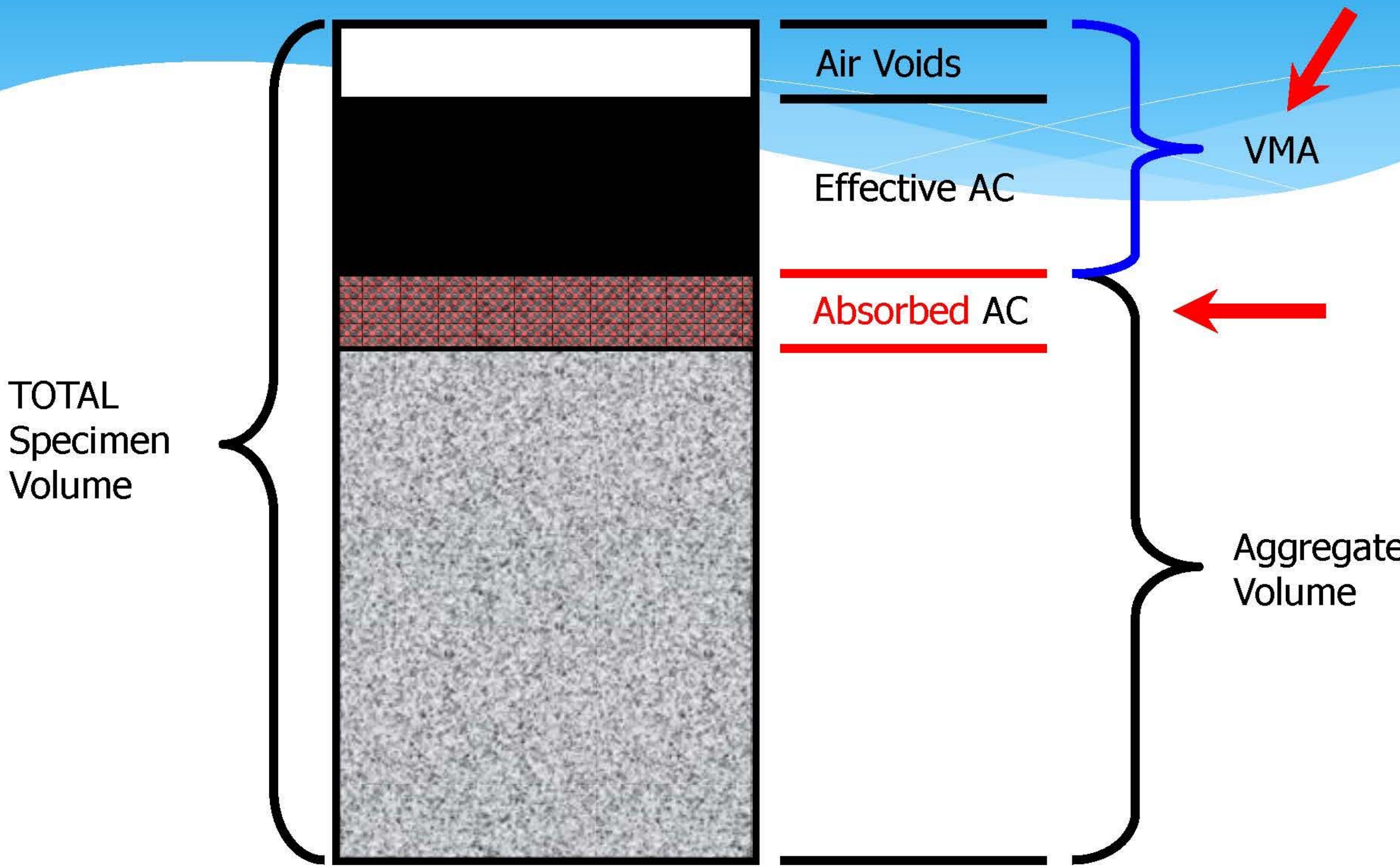
Terminology

- **Effective Asphalt Content (P_{be})** – % of non-absorbed asphalt
- $P_{be} = P_b - P_{ba}$
- P_{ba} calculated using G_{se} and G_{sb}
- *Gravimetric*

Compacted Specimen with Asphalt Removed



VMA = Air Voids + Effective AC



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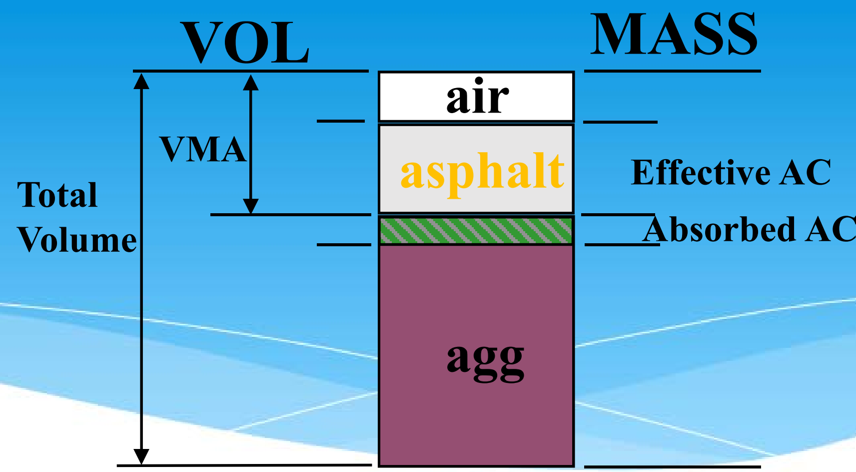
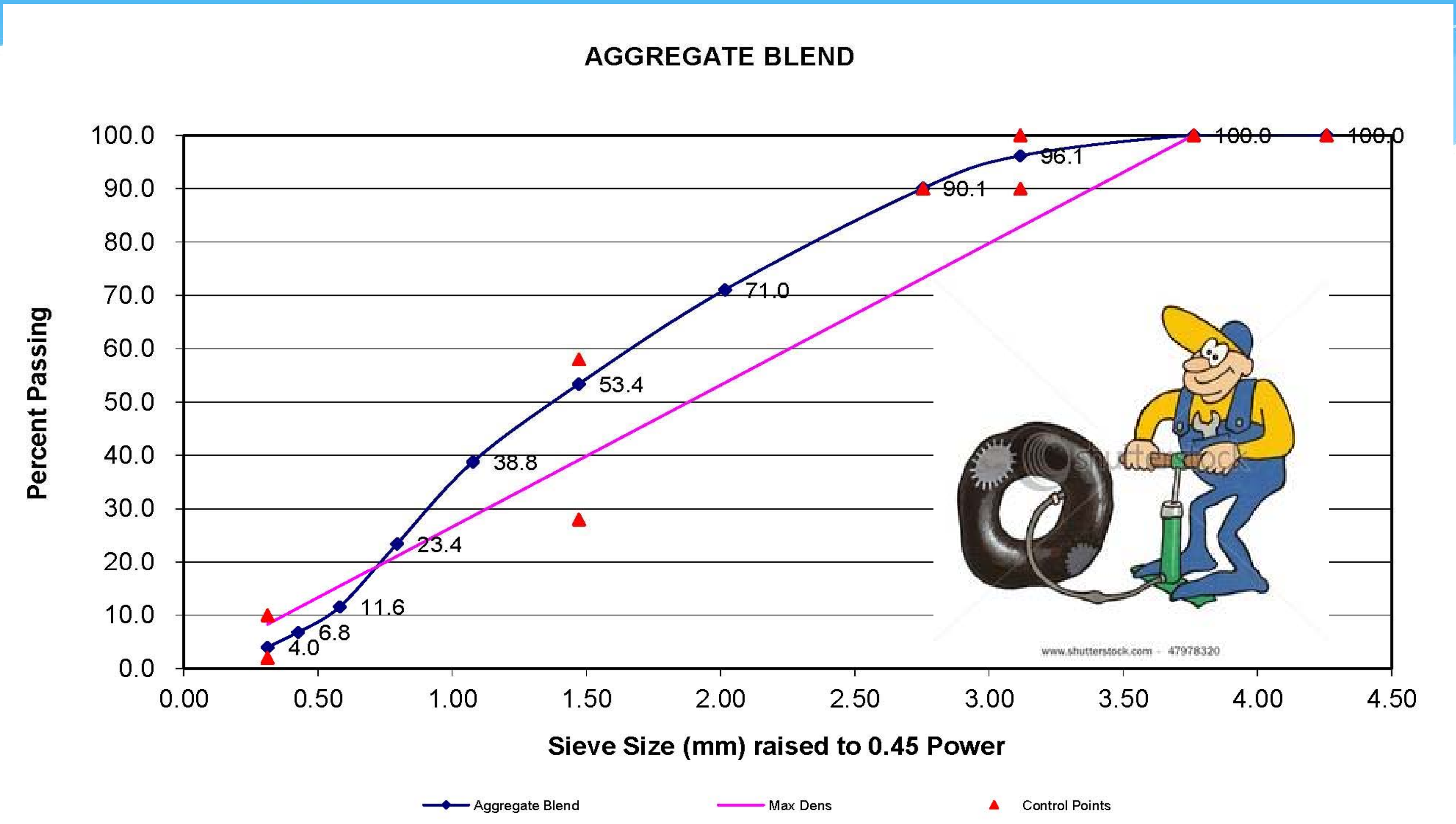
Voids in Mineral Aggregate (VMA)

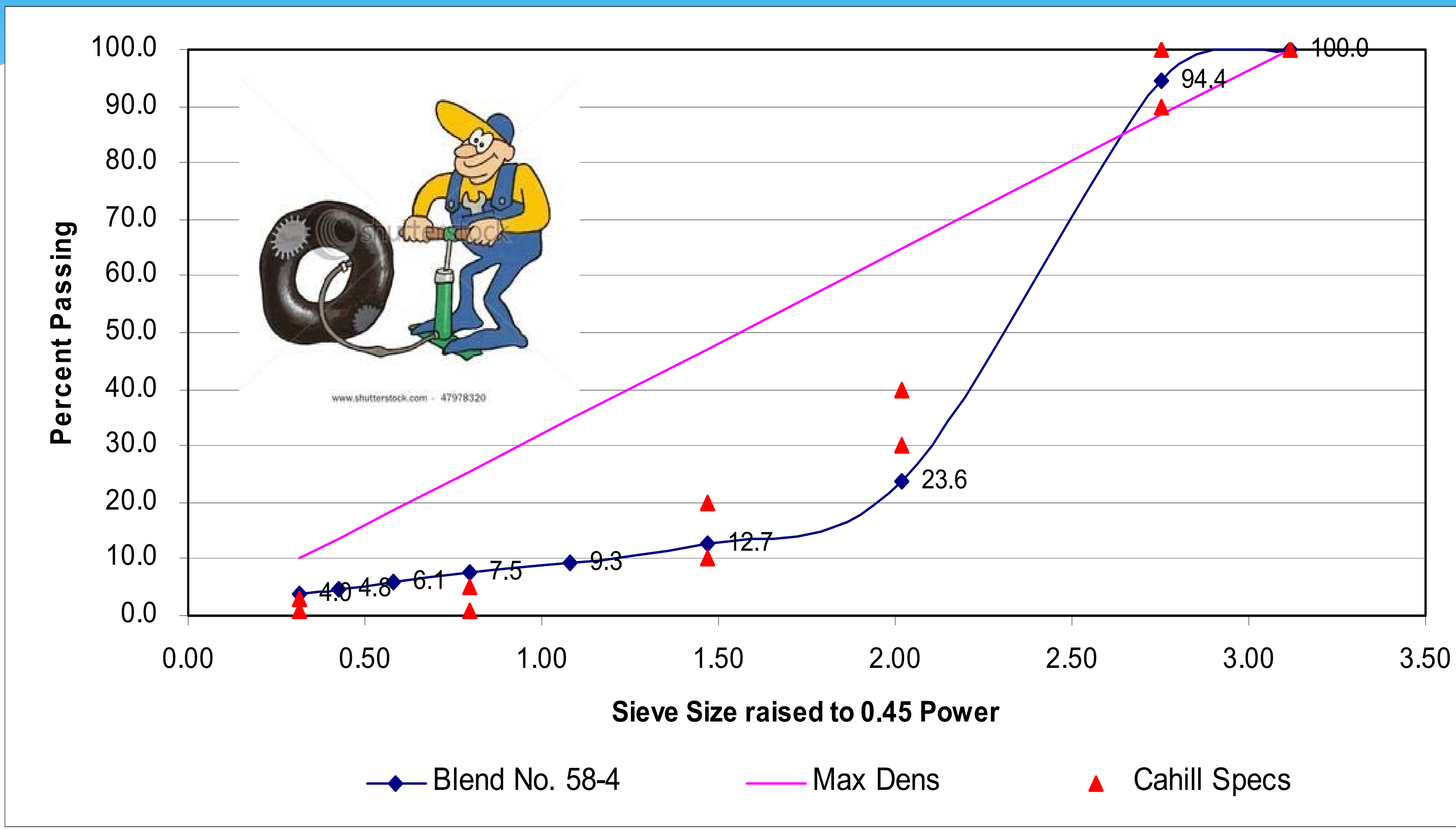


- Definition: *volume* of intergranular void space in a compacted mix % by volume total mix.
- VMA = 100-[G_{mb} x (100-P_b)/G_{sb})
- Strongly influenced by gradation.
- Increased VMA = Increased Asphalt Content = Increased Film Thickness

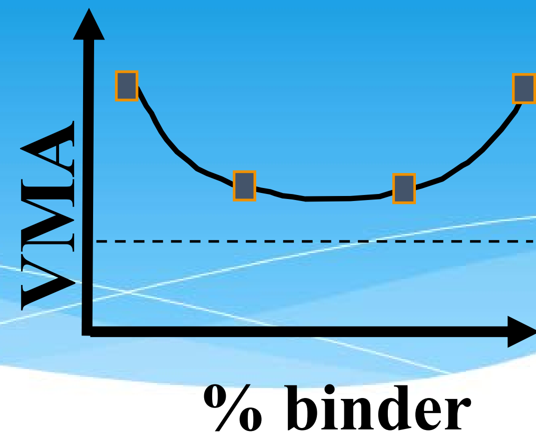
12.5 mm Mix - .45 Power Curve



9.5 mm Porous - .45 Power Curve

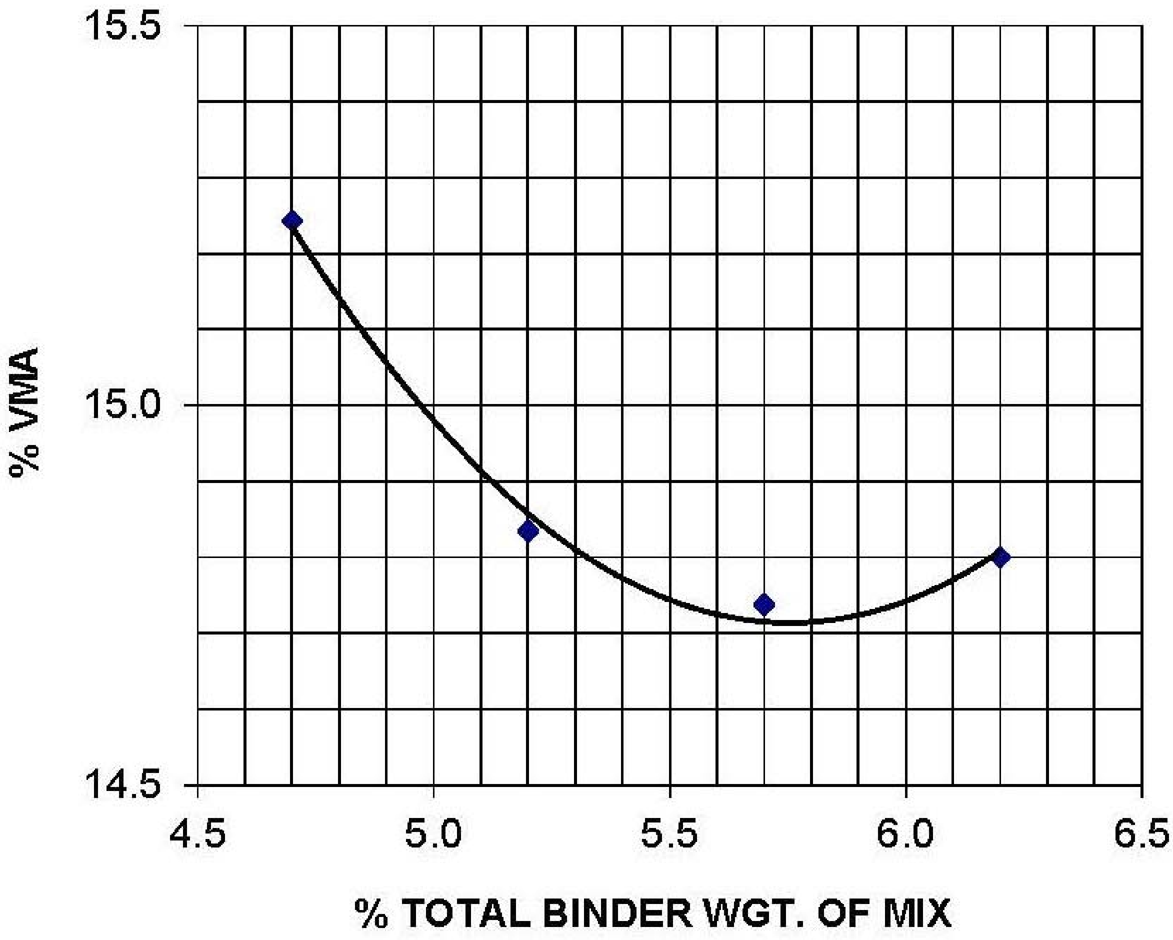


Mix VMA Requirements
Voids in the Mineral Aggregate



Nom Max Size (Grade)	(mm)	Minimum VMA %
5	9.5	15.0 (15.5)
4	12.5	14.0 (14.5)
3	19	13.0
2	25	12.0
1	37.5	11.0

VMA vs. Asphalt Content



Terminology

- **Voids Filled with Binder (VFB or VFA)** – The percentage of VMA filled with asphalt binder.
- VFB = 100 x (VMA-V_a)/VMA
- Generally required to be between about 65 – 75%.
- *Volumetric*

AASHTO M323 Volumetric Properties (Compacted Mix)

	9.5-mm	12.5-mm	19.0-mm	25.0-mm
Voids in Mineral Aggregate, %	15.0	14.0	13.0	12.0
Air Voids, %	4.0	4.0	4.0	4.0
Minimum Effective Volume Asphalt Binder, %	11.0	10.0	9.0	8.0

Volumetric Properties

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Asphalt Outside the Aggregate

* Convert percent volume to percent weight

$$P_{be} = \frac{V_{be}}{2.25}$$

	9.5-mm	12.5-mm	19.0-mm	25.0-mm
Percent by Volume	11.0%	10.0%	9.0%	8.0%
Percent by Weight	4.4%	4.0%	3.6%	3.2%

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Values approximate depending upon specific gravity of aggregates

Why Focus on Effective Binder Content?

Why not just focus on total binder content?

SAME **VMA** and Different AC Contents?

* **Design 1**
  * **VMA** = 13.4%
  * Voids = 4.0%
  * **Total AC = 4.6%**
* **Design 2**
  * **VMA** = 13.4%
  * Voids = 4.0%
  * **Total AC = 4.8%**

- The Difference Is Asphalt Absorption

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How Much Asphalt is Enough?

* Total Asphalt Content
  * Inside Rock
  * Outside Rock

Values approximate depending upon specific gravity of aggregates and actual absorption

Water Absorption	9.5-mm	12.5-mm	19.0-mm	25.0-mm
0%	4.4%	4.0%	3.6%	3.2%
1%	4.9%	4.5%	4.1%	3.7%
2%	5.6%	5.2%	4.8%	4.4%
3%	6.3%	5.9%	5.5%	5.1%
4%	7.0%	6.6%	6.2%	5.8%

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Superpave fixed the rutting problem but lowered effective asphalt contents which led to loss of durability

WisDOT Aggregate Specifications

TABLE 460-1 AGGREGATE GRADATION MASTER RANGE AND VMA REQUIREMENTS

SIEVE	PERCENT PASSING DESIGNATED SIEVES						
	NOMINAL SIZE						
	No. 1 (37.5 mm)	No. 2 (25.0 mm)	No.3 (19.0 mm)	No. 4 (12.5 mm)	No. 5 (9.5 mm)	SMA No. 4 (12.5 mm)	SMA No. 5 (9.5 mm)
50.0-mm	100						
37.5-mm	90 –100	100					
25.0-mm	90 max	90 -100	100				
19.0-mm	___	90 max	90 -100	100		100	
12.5-mm	___	___	90 max	90 -100	100	90 - 97	100
9.5-mm	___	___	___	90 max	90 -100	58 - 72	90 - 100
4.75-mm	___	___	___	___	90 max	25 - 35	35 - 45
2.36-mm	15 – 41	19 - 45	23 - 49	28 - 58	32 - 67	15 - 25	18 - 28
75-µm	0 – 6.0	1.0 - 7.0	2.0 - 8.0	2.0 - 10.0	2.0 - 10.0	8.0 - 12.0	10.0 - 14.0
% MINIMUM VMA	11.0	12.0	13.0	14.0[1]	15.0[2]	16.0	17.0

[1] 14.5 for LT and MT mixes.

[2] 15.5 for LT and MT mixes.

Minimum VMA requirements increased for LT and MT mixes

Increase Asphalt Content by Lowering Voids

Effective with December 2016 Letting **ASP-6**

ADDITIONAL SPECIAL PROVISION 6

ASP 6 - Modifications to the standard specifications

Make the following revisions to the standard specifications:

460.2.1 General

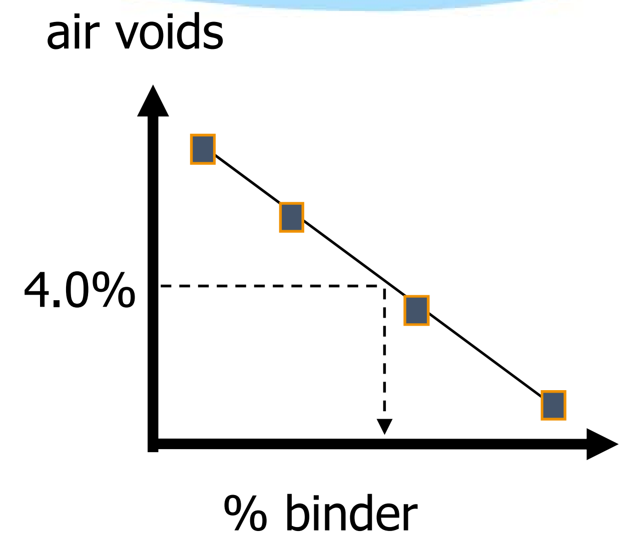
Replace the entire text with the following effective with the December 2016 letting:

(1) Furnish a homogeneous mixture of coarse aggregate, fine aggregate, mineral filler if required, SMA stabilizer if required, recycled material if used, warm mix asphalt additive or process if used, and asphaltic material. Design mixtures conforming to table 460-1 and table 460-2 to 4.0% air voids to establish the aggregate structure.

(2) Determine the target JMF asphalt binder content for production from the mix design data corresponding to 3.0% air voids (97% Gmm) target at the design the number of gyrations (Ndes). Add liquid asphalt to achieve the required air voids at Ndes.

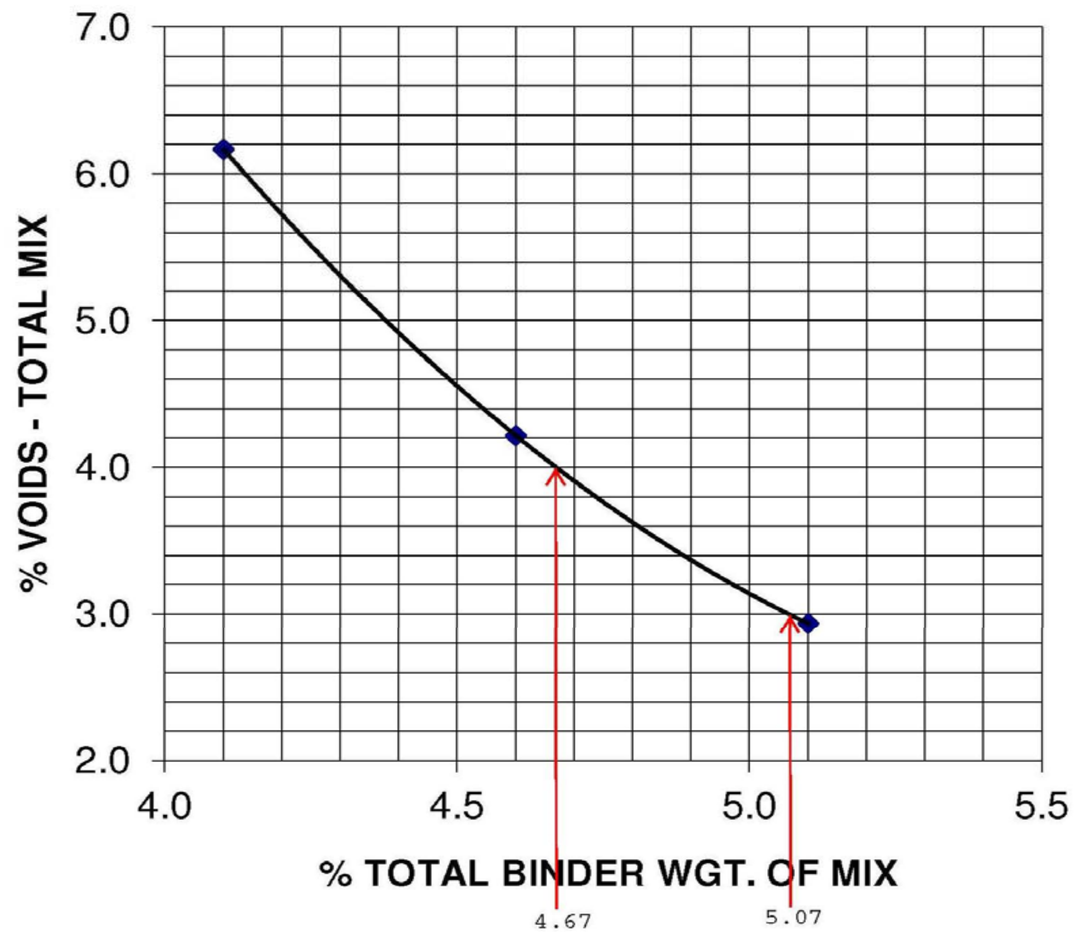
Determine Asphalt Content @ 4.0% Voids

Mixture Type	**Design Gyrations**
LT	40
MT	75
HT	100



Use linear regression to determine asphalt content at 3.0% air voids

Asphalt Content @ 4.0% & 3.0% Voids



Increase in P_b goes directly to P_{be} = increased film thickness

Bottom Line - VMA is King

- Allows for increased effective asphalt volume (film thickness) while maintaining voids.

- Improves durability while maintaining rut resistance.

Balance the Mix Design

asphalt institute

Not to be confused with
"Balanced Mix Designs"

Smooth Quiet Ride
Skid Resistance

Strength/
Stability

Rut Resistance

Shoving

Flushing
Resistant

Durability

Crack
Resistance

Raveling

Permeability

DON'T ATTACK ONE HALF AT THE EXPENSE OF THE OTHER HALF!!

Dave Johnson – Asphalt Institute, 2016

Calculating Effective Binder Content

What goes into the calculation?

Calculation of Effective Asphalt Content

$$P_{be} = P_b - \left(\left(\frac{P_{ba}}{100}\right) \times (100 - P_b)\right)$$

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

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

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

"Measurement of Effective Asphalt Content"
Canadian Technical Asphalt Association 2016

Gerry Huber – Heritage Research Group, 2017

12.5-mm NMPS Mixture Properties

* P_b	5.4%
* G_{mb}	2.419
* G_{mm}	2.520
* G_{sb}	2.672
* G_b	1.030
* VMA	14.4%
* Air Voids	4.0%
* P_{ba}	1.05%

* Which measured value has most impact on effective asphalt calculation?

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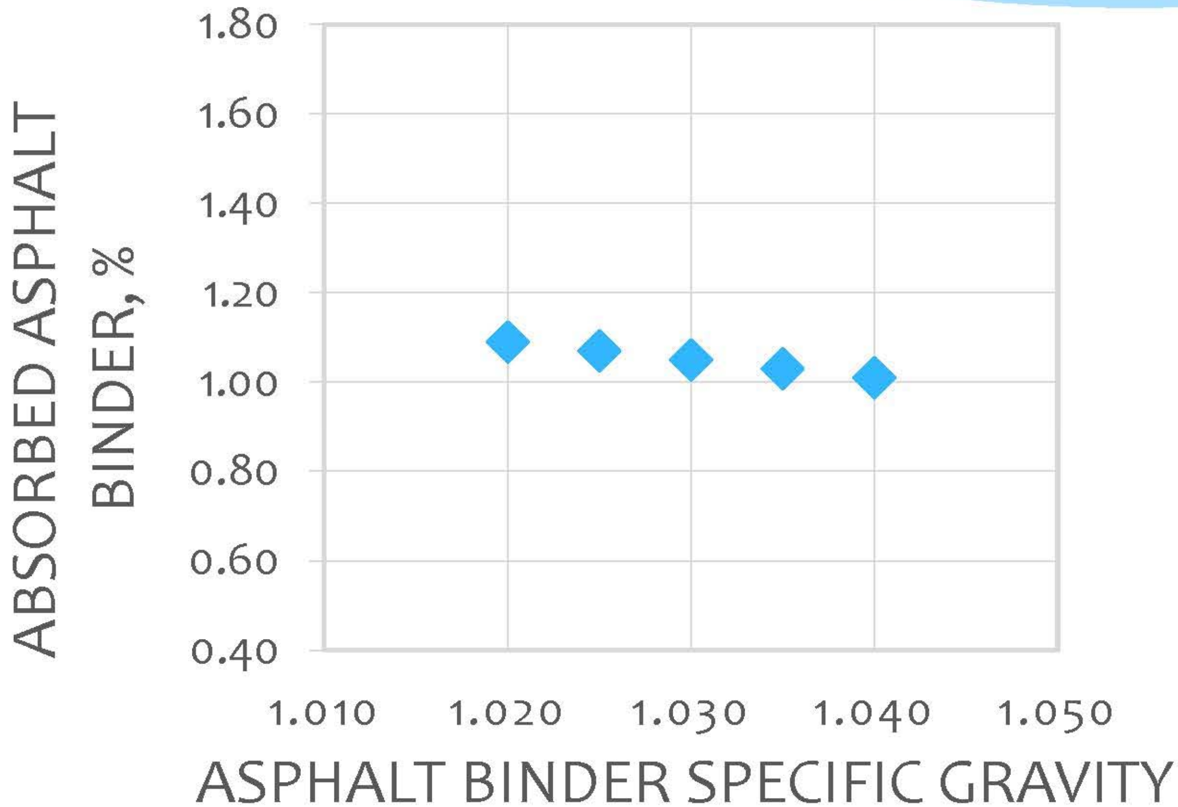
Asphalt Binder Specific Gravity



Range
0.1%

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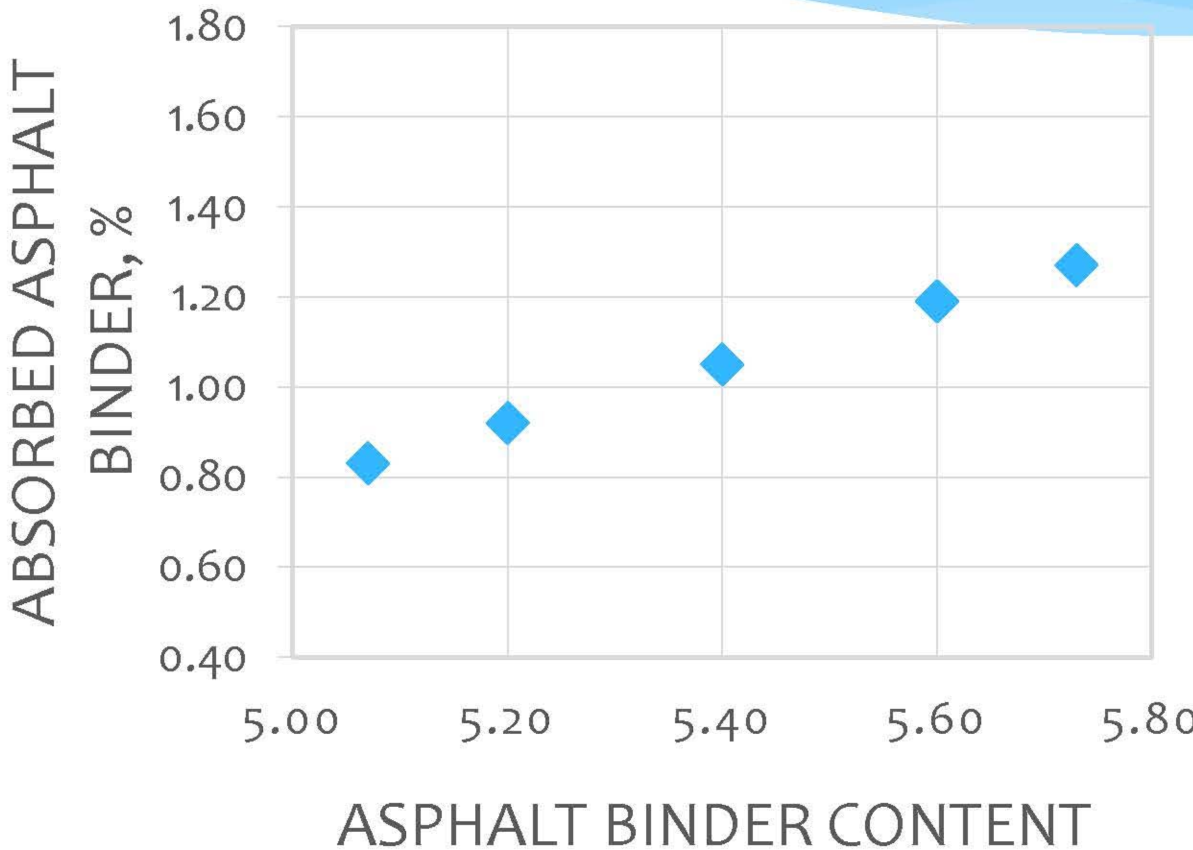
Asphalt Binder Content



Range
0.4%

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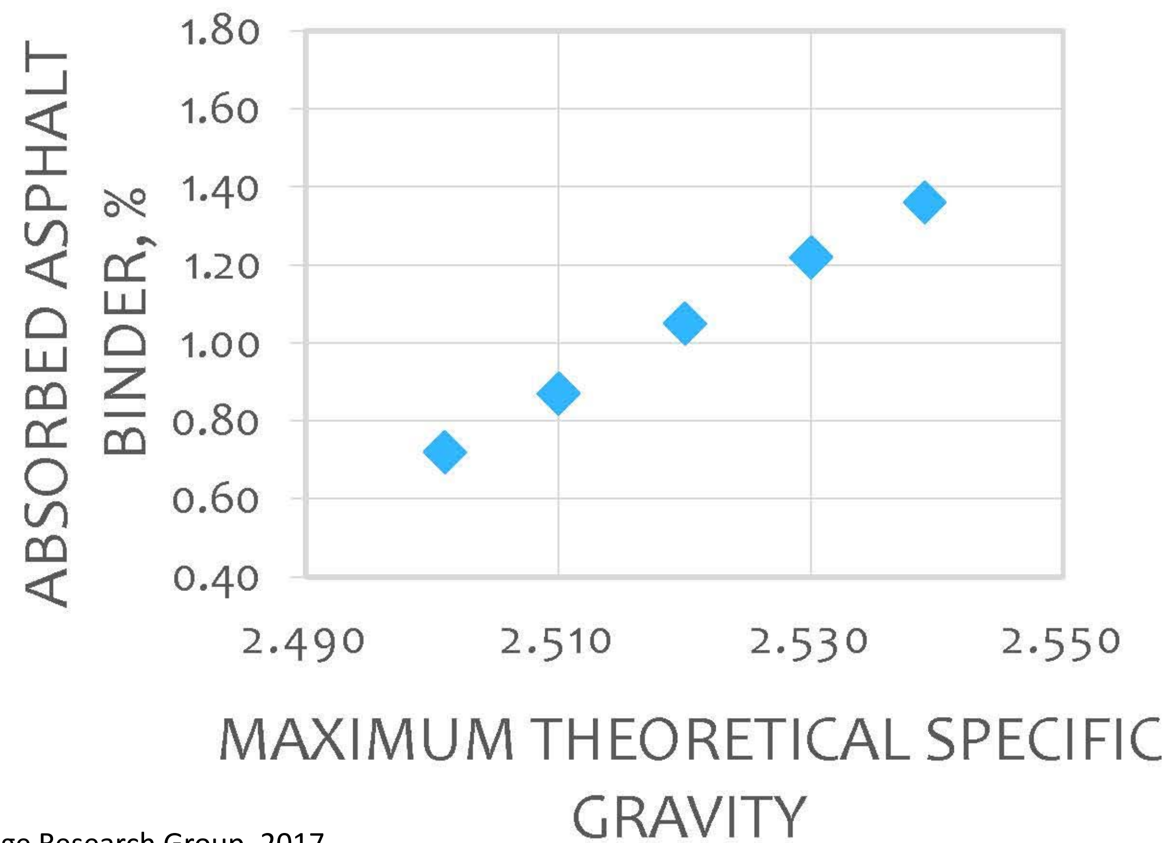
Maximum Specific Gravity



Range 0.7%

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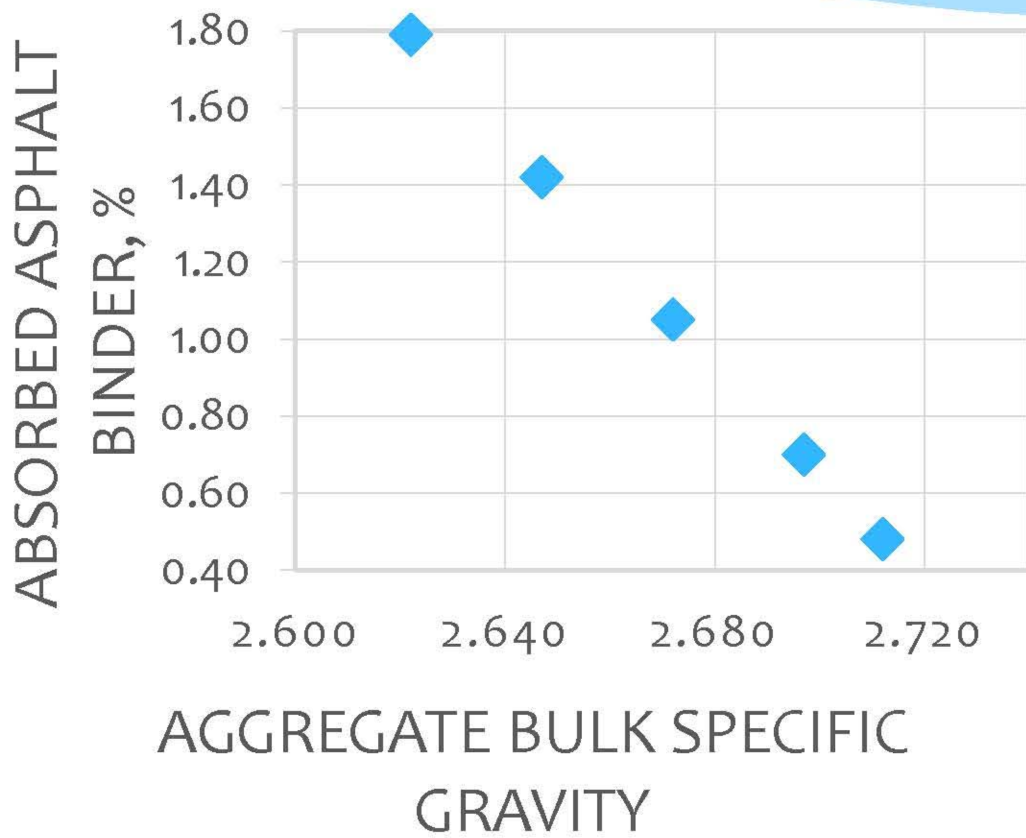
Aggregate Bulk Specific Gravity



Range
1.3%

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Aggregate Bulk Specific Gravity

* AASHTO D2S
  * Coarse Aggregate 0.038
  * Fine Aggregate 0.066

* 50:50 Blend
  * Say 0.052

Effect of Incorrect G_{sb} (+/- 0.052)

Property	2.620	2.672	2.724
Voids in Mineral Aggregate (VMA)	14.4%	14.4%	14.4%
Volume of Effective Binder (V_{be})	10.4%	10.4%	10.4%
Calculated Absorbed Asphalt Content (P_{ba})	1.80%	1.05%	0.48%
Effective Asphalt Content (P_{be})	4.46%	4.41%	4.41%
Asphalt Binder Content (P_b)	6.15%	5.40%	4.87%

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With Correct G_{sb}

Property	2.672	2.672	2.672
Asphalt Binder Content (P_b)	6.15%	5.40%	4.87%
Voids in Mineral Aggregate (VMA)	16.0%	14.4%	13.2%
Volume of Effective Binder (V_{be})	12.0	10.4	9.2
Calculated Absorbed Asphalt Content (P_{ba})	1.07%	1.05%	1.05%
Effective Asphalt Content (P_{be})	5.15%	4.41%	3.87%

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How do performance tests tie into empirical properties??

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Rutting Test Failure

- Materials
  - Aggregate
    - ✓ Crushed faces
    - ✓ Fine Aggregate Angularity
    - Surface chemistry
  - Asphalt binder
    - ? High temperature PG
    - Low temperature PG
- Proportions
  - ✗ Air voids
  - Volume effective asphalt
  - ✗ Voids filled with Asphalt

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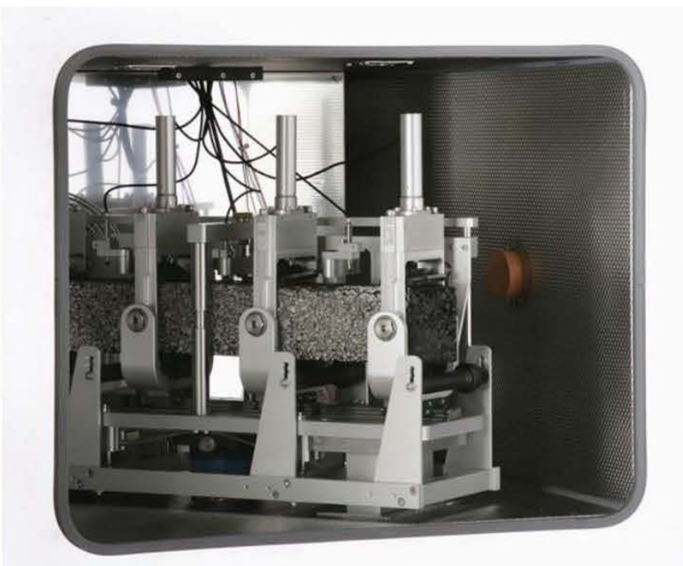
Fatigue Cracking Test Failure



- Materials
  - Aggregate
    - Crushed faces
    - Fine Aggregate Angularity
    - Surface chemistry
  - Asphalt binder
    - ? High temperature PG
    - Low temperature PG
- Proportions
  - Air voids
  - ✓ Volume effective asphalt
  - Voids filled with Asphalt

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Low Temperature Cracking Test Failure

- Materials
  - Aggregate
    - Crushed faces
    - Fine Aggregate Angularity
    - Surface chemistry
  - Asphalt binder
    - High temperature PG
    - ? Low temperature PG
- Proportions
  - Air voids
  - ✓ Volume effective asphalt
  - Voids filled with Asphalt

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Moisture Damage Test Failure

- Materials
  - Aggregate
    - Crushed faces
    - Fine Aggregate Angularity
    - ✓ Surface chemistry
  - Asphalt binder
    - High temperature PG
    - Low temperature PG
- Proportions
  - Air voids
  - ? Volume effective asphalt
  - Voids filled with Asphalt

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Aging Relationship to Empirical Properties

* Materials
  * Aggregate
    * Crushed faces
    * Fine Aggregate Angularity
    * Surface chemistry
  * Asphalt binder
    * High temperature PG
    * Low temperature PG
* Proportions
  * Air voids
  * ✓ Volume effective asphalt
  * ✓ Voids filled with Asphalt

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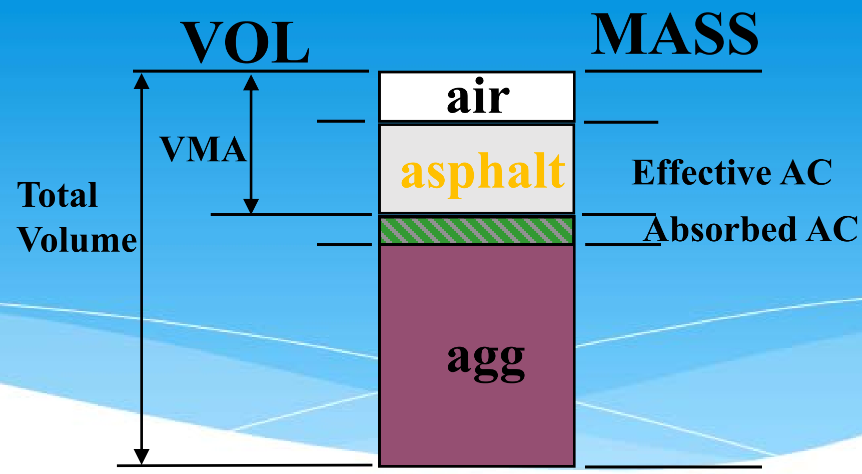
Bottom Line - VMA is King

- Allows for increased effective asphalt volume (film thickness) while maintaining voids.
- Improves durability while maintaining rut resistance.

Volumetrics



- Relatively inexpensive testing and can be quickly determined.
- Has been used to predict performance in past.
- Will likely still play a role in the age of performance testing (surrogate properties).

Thank you!!

Questions?