Troubleshooting Mix Designs

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Asphalt Mix Design

Strength/ Stability

Rut Resistance

Raveling

Durability

Crack Resistance

Shoving

Flushing

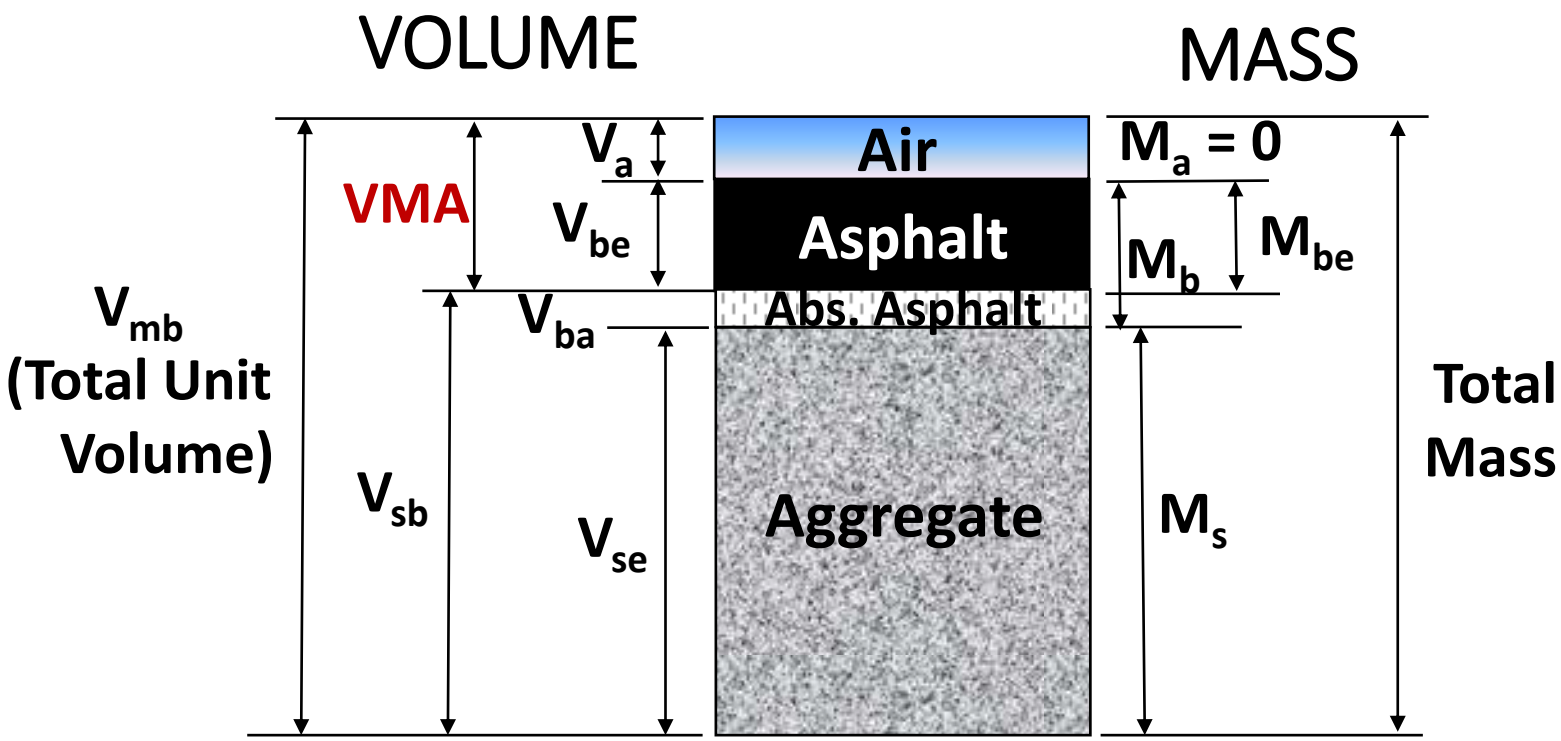
Asphalt Mix Characteristics

A layer of asphalt pavement has three components:

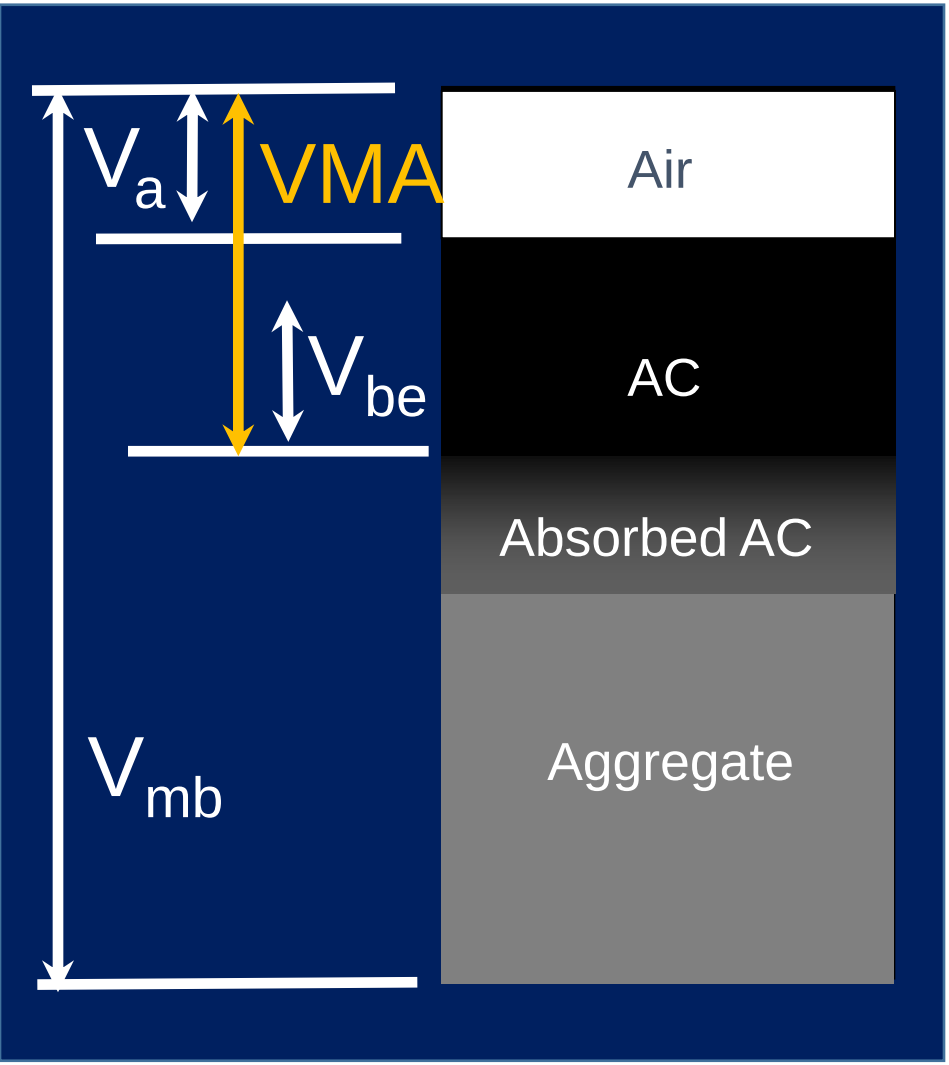
	Typical % By Mass:	Typical % By Volume:
1) Aggregate	94 - 96	83 - 84
2) Asphalt Binder	4 - 6	11 - 12
3) Air	0	4 - 7

Volumetrics

We evaluate the quality of the asphalt mixture by setting parameters on these three components, which have historically provided a good indication of a mixture's probable performance.



VMA



VMA is the volumetric void space created by the aggregate particles in an asphalt mixture. It is filled with the volume of air voids plus the volume of the binder not absorbed into the aggregate.

The mix needs a minimum VMA to have enough volume to hold the proper amount of air voids and the proper amount of binder.

VMA

Question:

Why can't you add the percent effective binder (P_{be}) to the percent air voids (P_a) to get the VMA?

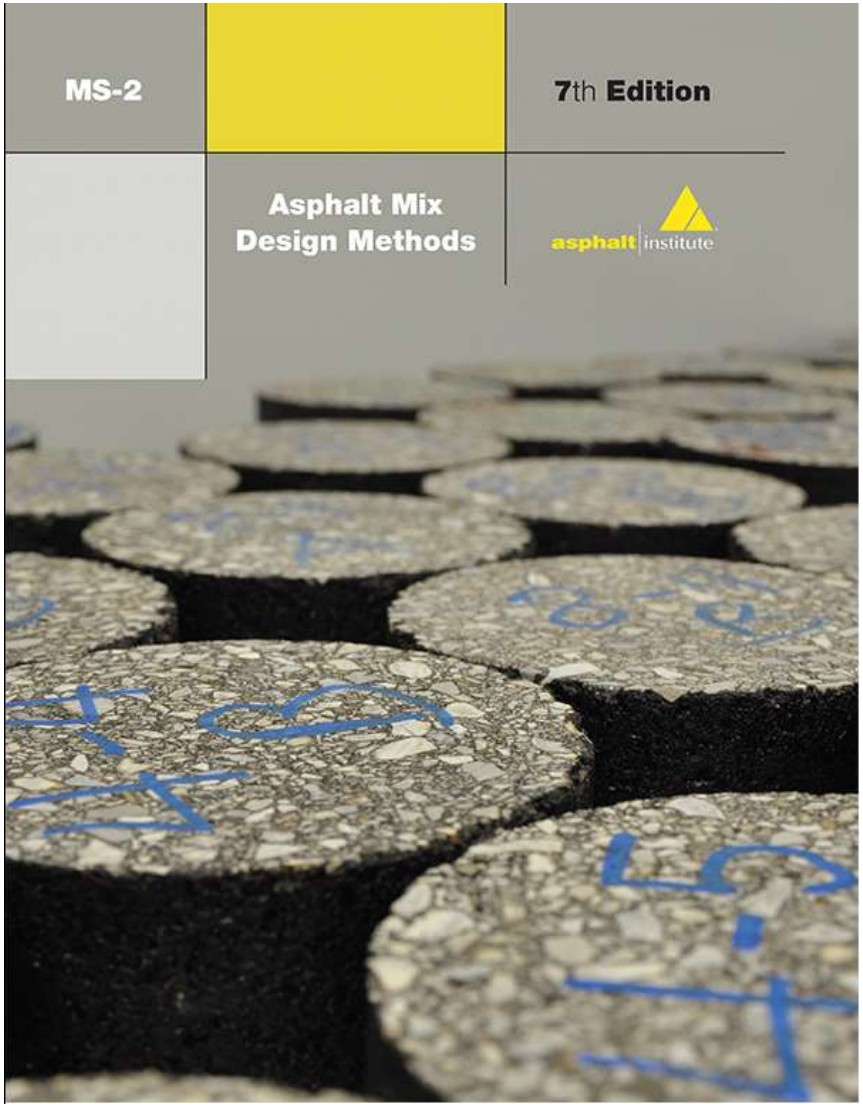
Answer:

Because P_{be} is a percentage by <u>mass</u> and P_a is a percentage by <u>volume</u>.

How do asphalt field mixes typically differ from the mix design?

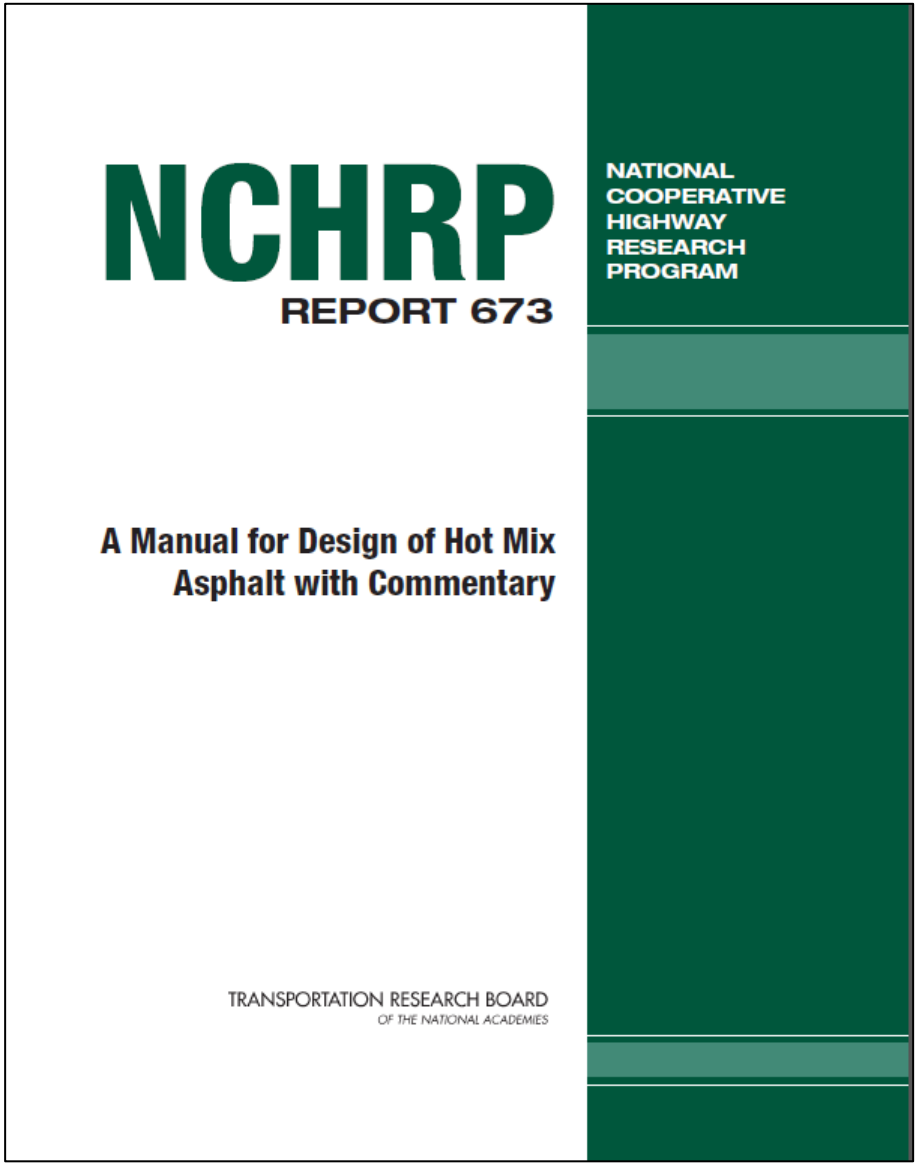
A drop in air voids and VMA

Drop in Air Voids and VMA



"The most common problem encountered in plant-produced mix is the failure to meet VMA and air voids volumetric parameters."

Drop in Air Voids and VMA



"By far the most common reason for adjusting a mix design during initial plant production is to adjust the air void content and VMA obtained during testing of laboratory-compacted specimens."

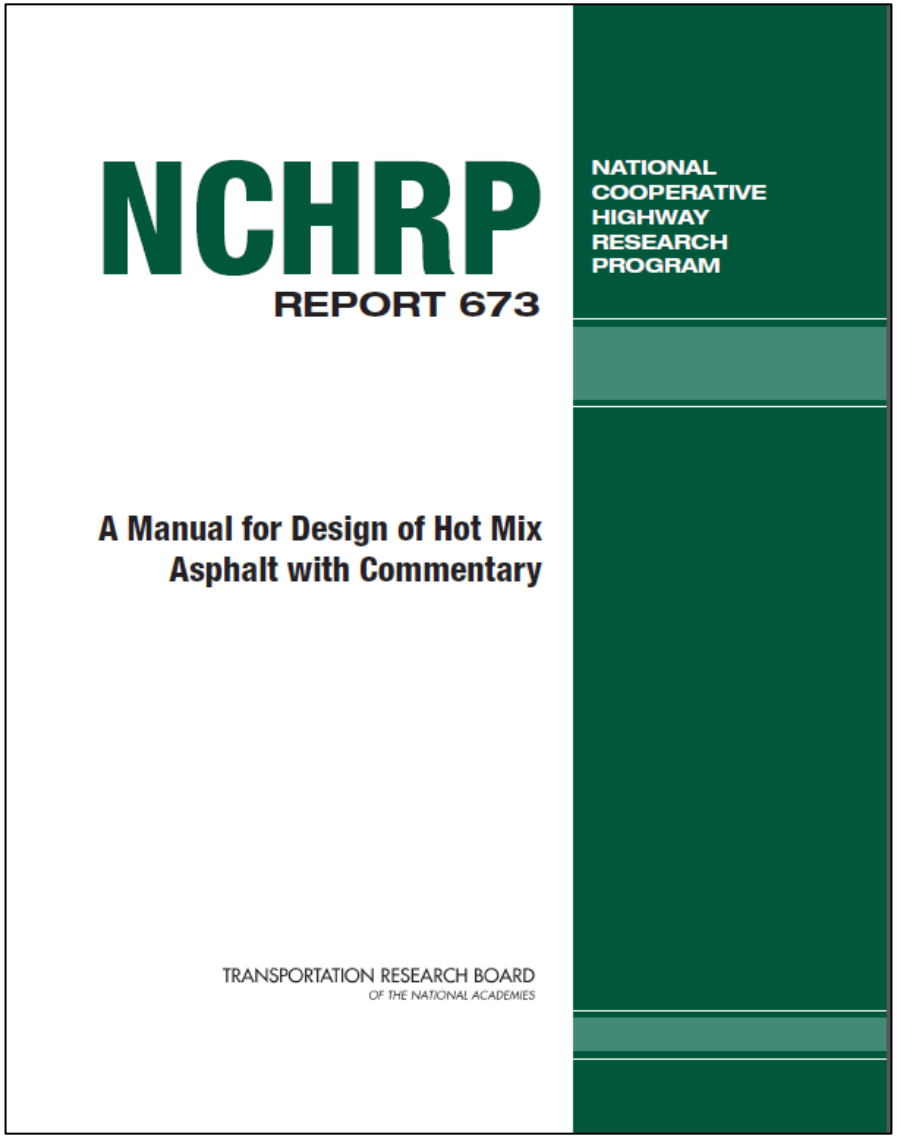
Why does this happen?

As aggregates are repeatedly handled in the field (stockpiled, loaded at quarry, unloaded at plant, loaded into cold feed bins, flow through the plant), the aggregate particles abrade each other, rounding off angular edges and creating additional fines.

Softer aggregates abrade and create more fines that harder aggregates

Rounding of angular edges during Micro Deval testing (field handling is not nearly as severe)

Drop in Air Voids and VMA



Average increase in fines during production at NCAT Test Track		
12.5 mm Superpave	19.0 mm Superpave	12.5 mm SMA
2.2%	**2.8%**	**3.5%**

"In the NCAT test track mixes, it appears that the increase in mineral filler during plant production increases with an increasing proportion of coarse aggregate in the HMA."

Why is this important?

1) *the rounding of aggregates allows the particles to pack together more tightly, reducing air voids*
2) *the generation of new fines fill more of the air voids created by the larger aggregate particles. This further reduces air voids and increases aggregate surface area, boosting the binder demand.*

The total space in between aggregate particles (VMA) is then reduced.

The binder content can be reduced to keep the % air voids constant, but then the asphalt film thickness is reduced.

Coupled with the binder demand created by the generated fines, the mix can become significantly under-asphalted.

Adequate VMA = space for proper air voids and proper binder content

Low VMA = space for proper air voids but not proper binder content

- or -

Low VMA = not enough space for proper air voids but enough for proper binder content

- Measuring the roadway density gives the user information about how well the contractor consolidated the mix during rolling operations, but gives no information about mix quality.
- Determining the gradation of field samples gives an indication of how well the field gradation matches the lab-designed mix, but gives no information regarding aggregate packing due to the loss of aggregate angularity during handling and production.
- Determining the binder content of field samples gives an indication of how well the field binder content matches the lab-designed mix, but gives no information regarding the change in film thickness on the aggregates or the lab-molded air void content.

The lab-molded air void content and VMA of field mixtures are the only parameters that allow the user to evaluate whether the mix still has enough binder for the proper film thickness at the proper lab-molded air void content.

Alaska DOT specifications do not include a field requirement for lab-molded air voids and VMA.

THE GOOD NEWS - that does not preclude determining lab-molded air voids and VMA on field mixtures as a means of troubleshooting mix designs.

Regarding specifications, the following is the typical ranking of the importance of commonly-measured asphalt parameters measured in the field (backed up by many PWL specs across the country that weight the parameters for pay):

1) Roadway Density
2) Lab-molded air voids/VMA
3) Binder content
4) Gradation

Designing Mixes for Success

How can this typical phenomenon be addressed at the mix design stage?

- Add extra fines over the JMD % Passing the No. 200 sieve to match the anticipated generation of fines due to handling and production. (Typically 0.5 - 2%, depending on the relative hardness of the aggregates you use)

Designing Mixes for Success

How can this typical phenomenon be addressed at the mix design stage?

- Design at a higher design VMA than required. Never design at the minimum limit. Best practices suggest designing at 0.5% higher if using high-quality aggregates to 1.0% (or even slightly higher) if using softer aggregates

SECTION 401

DESIGN PARAMETER	CLASS "A"	CLASS "B"
Voids in the Mineral Aggregate (VMA), %, Min.		
Type I	12.0	11.0
Type II	13.0	12.0
Type III, IV	14.0	13.0
Liquid Anti-Strip Additive**,%, Min.	0.30	0.30
RAP, %, Max.	15.0	25.0

TARGET?	
13.0	12.0
14.0	13.0
15.0	14.0

Designing Mixes for Success

For Mix Control in the Field - Aggregate Selection

If possible, use multiple aggregate types for maximum control.

- **For slight changes:** Include a larger and smaller chip, for example a 1/2" chip and a 3/8" chip. To increase air voids and VMA, decrease the % 1/2" chips and increase the % 3/8% chips *(be careful not to increase small chips such as pea gravel and 3/8" chips too much - they could make the mix tender and difficult to roll).* To decrease air voids and VMA, decrease the % 3/8" chips and increase the % 1/2% chips.
- **For larger changes:** Include both a screenings-type fine aggregate (8-12% passing the No. 200) and a washed screenings-type (3-6% passing the No. 200) fine aggregate. To increase air voids and VMA, decrease the screenings and increase the washed screenings.

** That typically means a five or six bin mix if you include natural sand and RAP.*

Mix Control in the Lab - Gradation Selection

Stockpile gradations change to some degree as aggregate is used and new material is brought in.

Do you:

- Batch to the gradation obtained from a quarry sample at the time the design is created?
- Batch to the gradation obtained from a plant stockpile sample at the time the design is created?
- Batch to historical averages of stockpile samples?

Designing Mixes for Success

Mix Control in the Lab - Batching

- Use an acceptable method to batch aggregates in a manner that is repeatable. That means a method whereby the aggregates are fractionated in some manner and batched back together uniformly - no scooping from sample sacks or buckets!

Aggregate Batching Methods

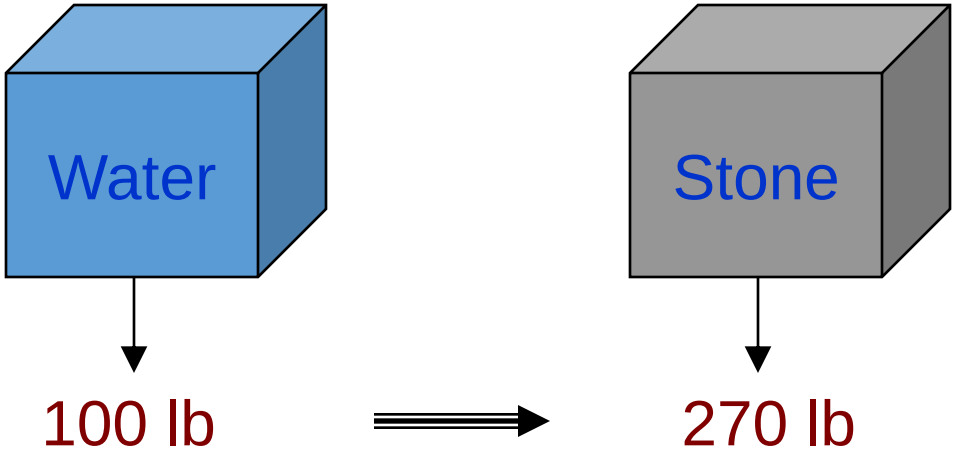
There are many different methods used for batching aggregates. Some are quick, but less accurate and repeatable. Some are more time-consuming, but more accurate and repeatable.

Scooping	Batching like Asphalt Batch Plant	Fractionating Each Aggregate Source
Least Accurate / Repeatable	More Accurate / Repeatable	Most Accurate / Repeatable
• Easiest method • Requires only one batching pan • Only used when little time available and/or accuracy not critical • **Not acceptable for mix design**	• Requires tray shaker • Uses 4-7 batching pans • Proper sampling/splitting techniques <u>must</u> be maintained • Locks in bin percentages, so less versatile • **Acceptable for mix design** ** A check can be run on the batch to verify gradation*	• Requires tray shaker • Uses 16-40 batching pans • Proper sampling/splitting less important if aggregates are split into all size fractions • Total freedom in changing bin percentages - most versatile • **Acceptable for mix design** • **Acceptable for research**

Specific Gravity

- **Ratio of aggregate weight to the weight of an equal volume of water**
  - **Dimensionless number (no units attached)**

Specific Gravity = 2.70 means that the rock weighs 2.70 times an equal volume of water



Basic Specific Gravity Equation

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

Where:

G = Specific Gravity

M = Mass

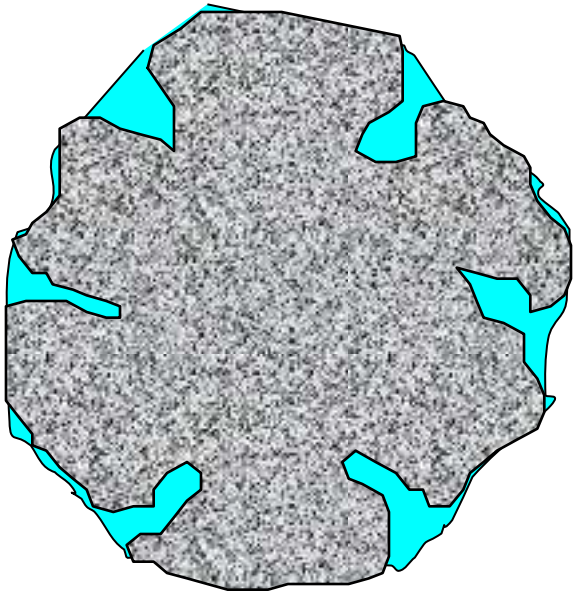
V = Volume

ρ = Density of Water (1 gm/cc)

Different Specific Gravity Evaluations

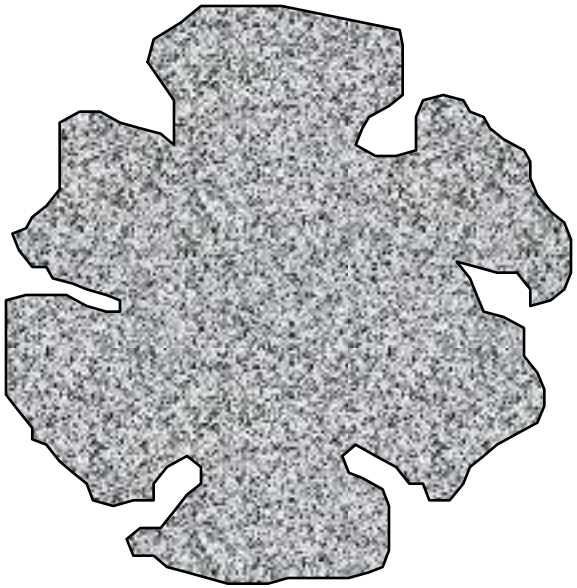
G_{sb}

Bulk Specific Gravity



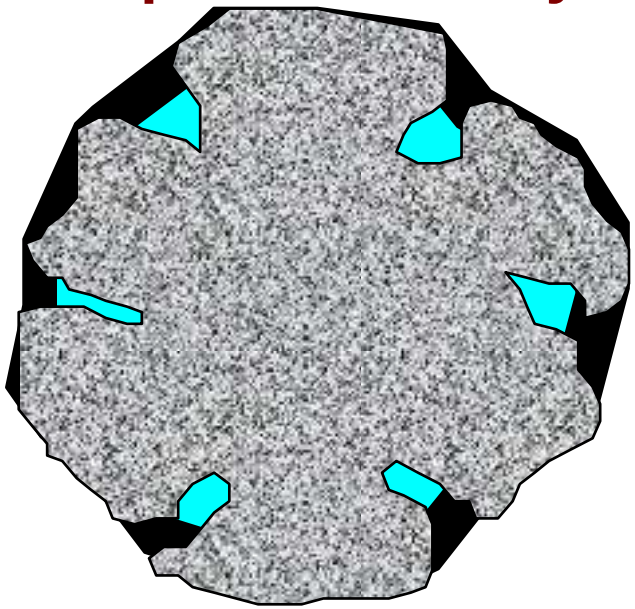
G_{sa}

Apparent Specific Gravity



G_{se}

Effective Specific Gravity



Determining G_{sb} for each aggregate source

	Percent Passing				
Sieve Size, mm	25% Agg 1	35% Agg 2	30% Agg 3	10% Agg 4	Composite Blend
25.0 (1”)	100.0	100.0	100.0	100.0	**100.0**
19.0 (3/4”)	92.0	100.0	100.0	100.0	**98.0**
12.5 (1/2”)	50.9	100.0	100.0	100.0	**87.7**
9.5 (3/8”)	28.7	91.8	100.0	100.0	**79.3**
4.75 (#4)	2.8	21.4	98.8	95.0	**46.3**
2.36 (#8)	2.6	3.0	66.9	88.8	**30.7**
1.18 (#16)	2.4	2.8	40.8	79.0	**21.7**
0.600 (#30)	2.2	2.6	27.0	65.3	**16.1**
0.300 (#50)	2.0	2.4	19.6	13.9	**8.6**
0.150 (#100)	1.8	1.6	15.7	2.2	**5.9**
0.075 (#200)	1.8	1.6	13.4	1.5	**5.2**
G_{sb}	**2.719**	**2.670**	**2.587**	**2.618**	**?**
G_{sa}	**2.766**	**2.745**	**2.741**	**2.711**	**?**

Determining G_{sb} for each aggregate source?

Best practice:

- during the trial stage, determine G_{sb} for each source and mathematically combine for maximum flexibility
- for the final design, physically combine all aggregates, split on No. 4 sieve, and determine the specific gravity of the combined coarse and fine fractions

Mix Control in the Lab - G_{sb} Determination

The value of G_{sb} used for the aggregate has a direct effect on the calculated VMA.

If the G_{sb} is overestimated, the calculated VMA will be higher than it actually is.

- In the coarse aggregate bulk gravity test procedure, this happens when the aggregate is towel-dried past SSD condition or when too much time passes between getting the aggregate to SSD condition and weighing it
- In the fine aggregate bulk gravity test procedure, this happens when the aggregate is allowed to dry to much in between the penultimate and final slump cone tests, or when too much time passes between getting the aggregate to SSD and weighing it

Mix Control in the Lab - G_{sb} Determination

The Rice's test for maximum theoretical specific gravity of the asphalt mixture is one of the most accurate and repeatable tests we have.

From it, the effective specific gravity, G_{se}, is calculated.

- Evaluate the quality of the G_{sb} determination using the G_{se} calculation as a reference.
- In no case should G_{sb} ever be greater in magnitude than G_{se}
- For aggregates with very little absorption, G_{sb} should be slightly lower in magnitude than G_{se}
- The higher the absorption, the greater the difference between G_{sb} and G_{se} should be.

RAP Aggregate Properties

- Measure consensus properties
- RAP aggregate specific gravity
  - Method #1
    - Split extracted aggregate into coarse (plus 4.75mm) and fine (minus 4.75mm) fractions
    - Determine the specific gravity of each size fraction
    - Advantages
      - Direct measure of specific gravity of RAP aggregate
    - Disadvantages
      - Extraction (or ignition oven) procedure can change aggregate properties
      - Sample may still contain asphalt or solvent, making it difficult to accurately determine specific gravity

MS-2
Section 11.3.2

RAP Aggregate Properties

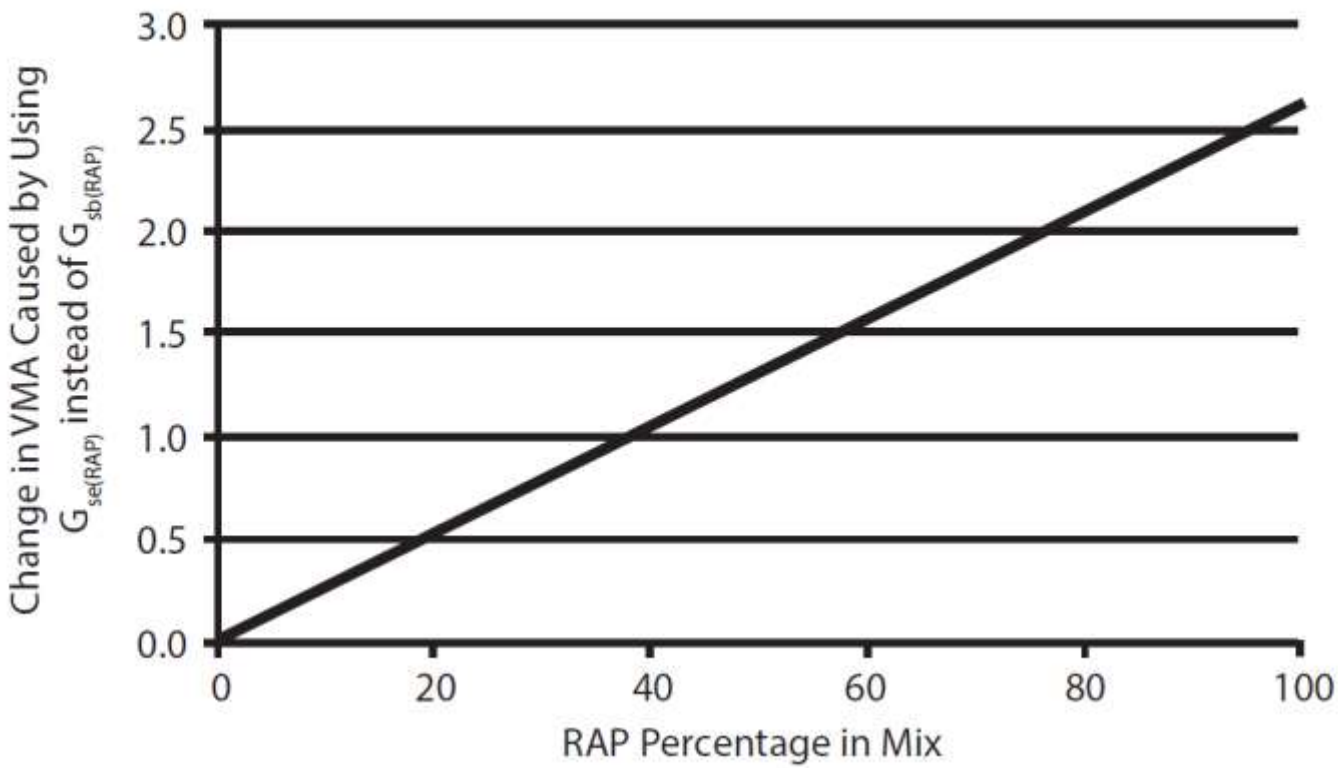
- Method #2
  - Determine G_{mm} of RAP (ASTM D2041)
  - Determine asphalt content of RAP
  - Calculate G_{se} of RAP and use instead of G_{sb} in volumetric calculations

  - Advantages
    - G_{se} easy to determine; more repeatable than G_{sb} measurements
  - Disadvantages
    - Use of G_{se} instead of G_{sb} <u>artificially</u> raises VMA

Effect of RAP on VMA

- At 40% RAP, the effect of using Gse (RAP) instead of Gsb(RAP) is a + 1% change in VMA.
- The VMA will <u>calculate</u> to be higher by approximately 1% than actual and can lead to a mix with insufficient asphalt binder content.

FIGURE 11.2 ***Effect of RAP Aggregate Specific Gravity on Calculated VMA (using example data)***



MS-2
Figure 11.2

RAP Aggregate Properties Example

RAP Aggregate Specific Gravity

G_{mm}(RAP) = 2.545

G_b(RAP) = 1.040

P_b(RAP) = 4.5%

Assume 1.04 - virgin binders typically between 1.01 and 1.03, RAP binder has aged, losing light fractions, remaining binder has higher percentage of heavier asphaltenes

$$G_{se}(RAP) = \frac{100 - P_b\,(RAP)}{\frac{100}{G_{mm}(RAP)} - \frac{P_b\,(RAP)}{G_b(RAP)}}$$

$$G_{se}(RAP) = \frac{100 - 4.5}{\frac{100}{2.545} - \frac{4.5}{1.040}} = 2.731$$

MS-2
Section 11.3.2.2

RAP Aggregate Properties

- RAP aggregate specific gravity
  - Method #2A
    - Determine G_{mm} of RAP (ASTM D2041)
    - Determine asphalt content of RAP
    - Calculate G_{se} of RAP
    - Assume asphalt absorption, P_{ba}, based on experience with materials
    - Calculate G_{sb} of RAP aggregate

    - Advantages - Method #2A
      - G_{se} easy to determine; more repeatable than G_{sb} measurements
      - Use of assumed P_{ba} allows for determination of G_{sb}
    - Disadvantages - Method #2A
      - Assumption of P_{ba}

RAP Aggregate Properties Example

RAP Aggregate Specific Gravity

G_{mm}(RAP) = 2.545

G_b(RAP) = 1.040

P_b(RAP) = 4.5%

P_{ba}(RAP) = 1.5%

$$G_{sb}(RAP) = \frac{G_{se}(RAP)}{\frac{P_{ba}(RAP) \times G_{se}(RAP)}{100 \times G_b(RAP)} + 1}$$

from previous example, G_{se}

$$G_{sb}(RAP) = \frac{2.731}{\frac{1.5 \times 2.731}{100 \times 1.040} + 1} = 2.628$$

P_{ba}(RAP), absorbed binder

Mix Control in the Lab - Binder Stiffness

Split out binder samples into smaller containers for use in mix design.

- Sometimes a lab obtains a 5-gallon pail of binder, which they keep in the mix design oven. They pour out what they need for each design as needed, constantly heating and reheating the large pail of binder.
- This stiffens the binder and affects the compaction rate.
- Best practice - split out binder samples into smaller containers (pint-sized) for use in mix design and only place the amount needed at one time in the oven.

Proper Conditioning Times

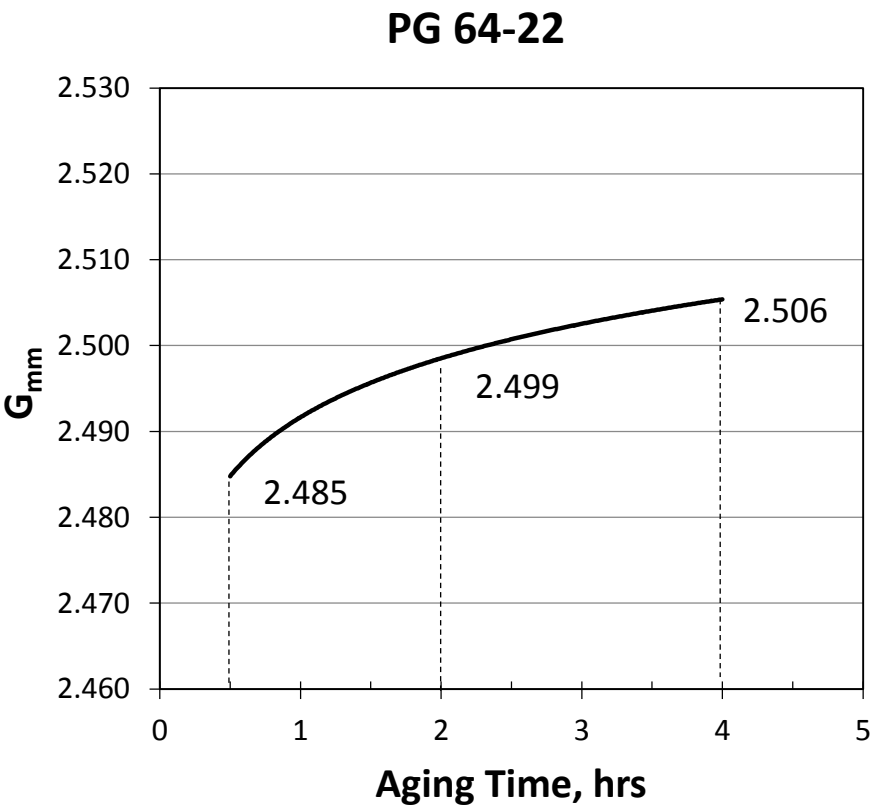
- Conditioning times on field QC testing may be reduced depending on sample location
- If preparing samples for performance testing, 4 hours is required according to AASHTO R30

Are volumetrics of the mix tested at 5 pm going to be the same as those tested at 8 the next morning after the mix has sat in the silo overnight?

- Conditioning time in the field should resemble conditioning time in the lab if you want comparable results

Short Term Aging Effects on G_{mm}

Kentucky Dolomitic Limestone - % Water Absorption (P_{wa}) ≈ 1.0%

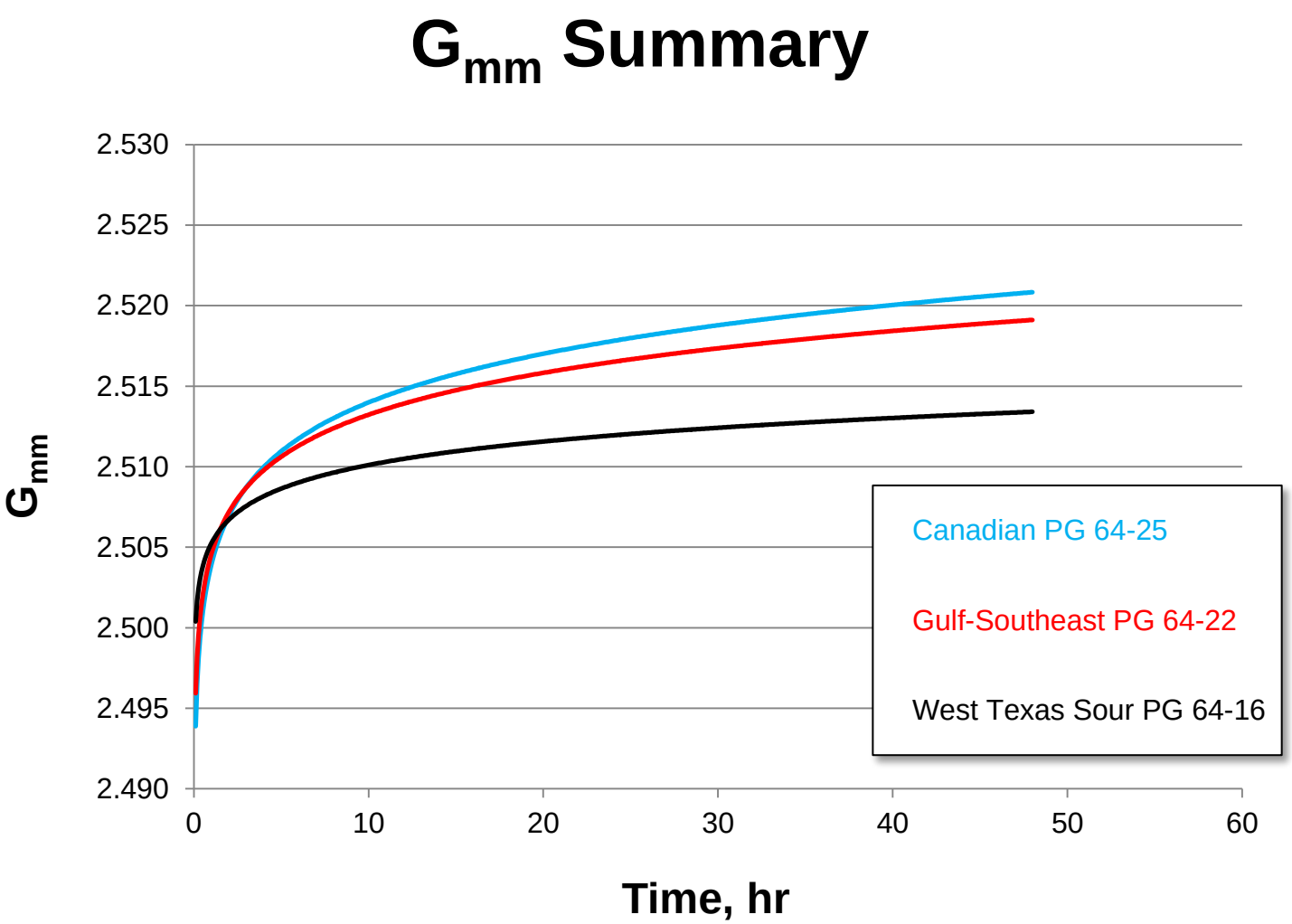


Time (hrs.)	G_{mm}	G_{mb}	P_a
0.5	2.485	2.399	3.46
2	2.499	2.399	4.00
4	2.506	2.399	4.27

Absorption continues to occur over a long period of time

Results in significant variation in G_{mm} over time

Long Term Aging Effects on G_{mm}



Curves will level out as P_{ba} approaches P_{wa}

Mix Design Changes in the Field?

The rule of thumb would be to never allow a different material or different source to be used than what is on the mix design. You need to know if your local agency allows:

- **Switching binder grade on same design (maybe)**
- **Switching binder source within same grade (maybe)**
- **Aggregate Types (<u>never</u>)**
- **Aggregate Sources (<u>never</u>)**
- **Changing % of each aggregate used (± small tolerance)**
- **Individual and combined aggregate gradations (maybe)**
- **Changing design binder content (maybe)**

Control -No. 200 in the Field

High percentages of - No. 200 material can cause tenderness and checking during compaction.
(Tenderness can also occur if all of the moisture is not driven out of the aggregate during production)

Summary

The mix design in the field will be different to some degree than the mix design as produced in the lab.

Understanding which parameters typically change and why will allow users to successfully troubleshoot mix design problems in the field.

Questions?