Back 2 Basics: Mix Design

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NAPA webinars

Objectives

- Describe the Superpave mixture requirements for a highway-class dense-graded asphalt paving mixture
  - AASHTO M 323
- Summarize the Superpave mix design process
  - AASHTO R 35

AASHTO Standards

Standard Practice for

Superpave Volumetric Design for Hot-Mix Asphalt (HMA)

AASHTO Designation: R 35-04

1. SCOPE

1.1. This standard for mix design evaluation uses aggregate and mixture properties to produce a hot-mix asphalt (HMA) job-mix formula. The mix design is based on the volumetric properties of the HMA in terms of the air voids, voids in the mineral aggregate (VMA), and voids filled with asphalt (VFA).

1.2. This standard may also be used to provide a preliminary selection of mix parameters as a starting point for mix analysis and performance prediction analyses that primarily use T 320 and T 322.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 320, Performance-Graded Asphalt Binder
- M 323, Superpave Volumetric Mix Design
- R 30, Mixture Conditioning of Hot-Mix Asphalt (HMA)
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 100, Specific Gravity of Soils

Standard Specification for

Superpave Volumetric Mix Design

AASHTO Designation: M 323-07

1. SCOPE

1.1. This specification for Superpave volumetric mix design uses aggregate and mixture properties to produce a hot-mix asphalt (HMA) job-mix formula.

1.2. This standard specifies minimum quality requirements for binder, aggregate, and HMA for Superpave volumetric mix designs.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

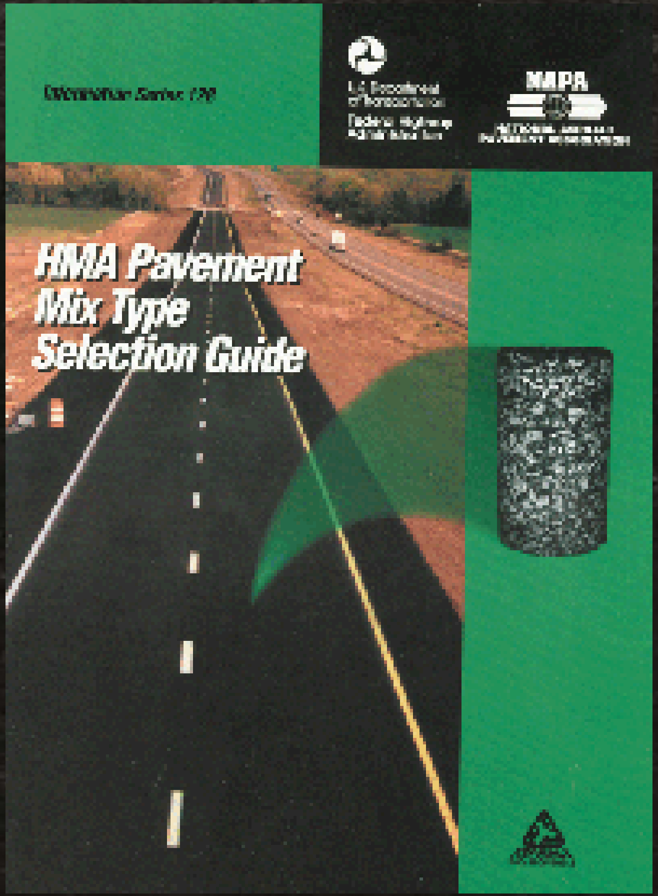
2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:
- M 320, Performance-Graded Asphalt Binder
- R 35, Superpave Volumetric Design for Hot-Mix Asphalt (HMA)
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 164, Quantitative Extraction of Asphalt Binder from Hot-Mix Asphalt (HMA)
- T 170, Recovery of Asphalt from Solution by Abson Method
- T 176, Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
- T 283, Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage
- T 304, Uncompacted Void Content of Fine Aggregate
- T 308, Determining the Asphalt Binder Content of Hot-Mix Asphalt (HMA) by the Ignition Method
- T 312, Preparing and Determining the Density of Hot-Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

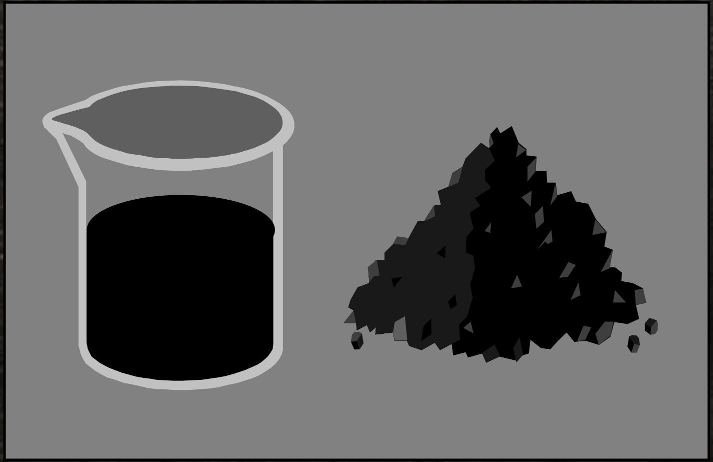
Mix Type Selection

- Select the right mix type for the pavement application
  - type of traffic/loads
  - layer-specific needs

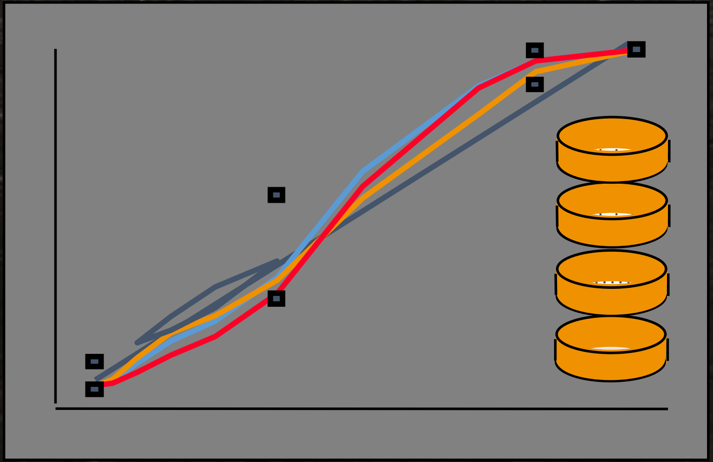
NAPA Publication IS-128



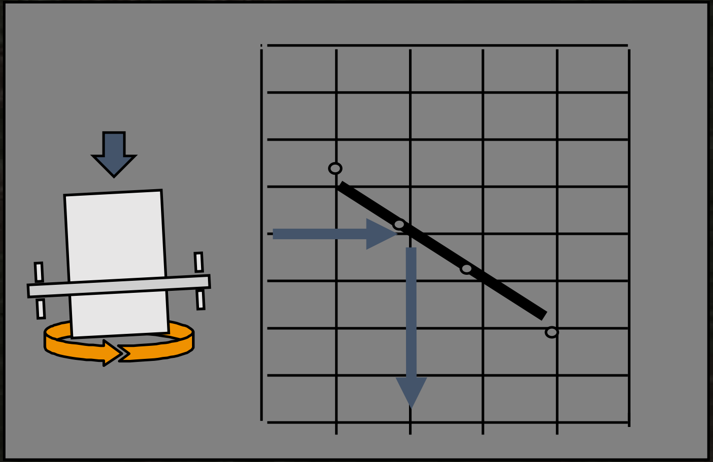
4 Steps of Superpave Mix Design



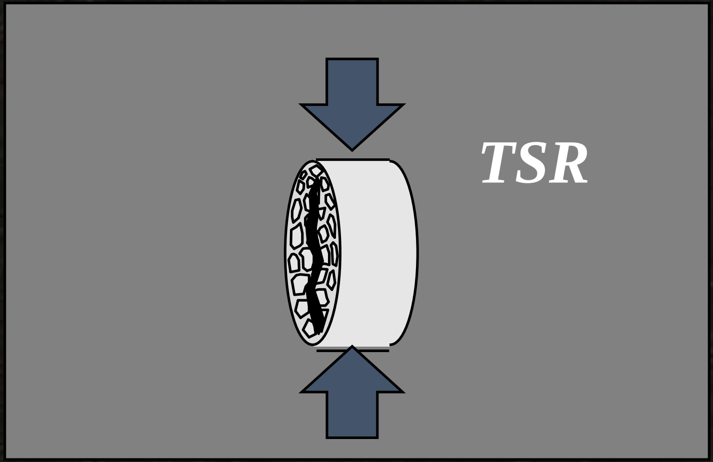
1. Materials selection



2. Design aggregate structure



3. Design binder content



4. Moisture sensitivity

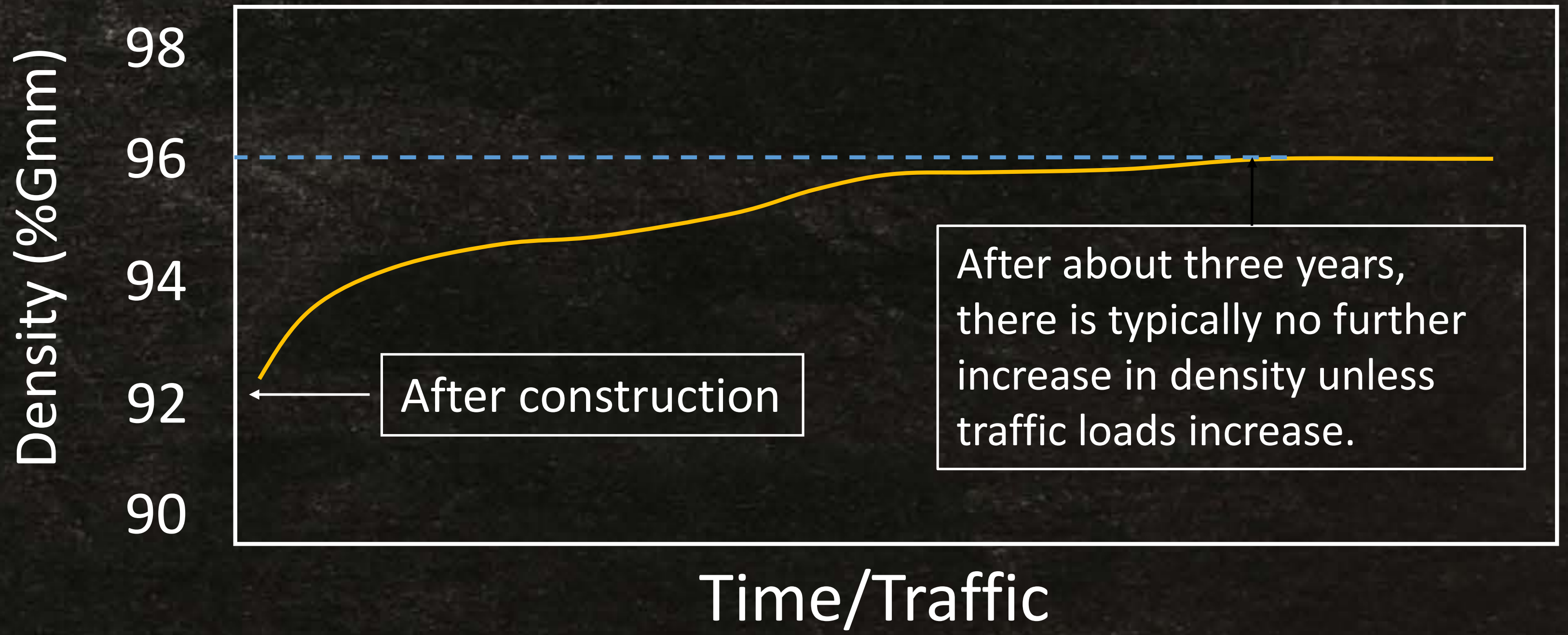
Pre-Mix Design
Selection of Mixture Requirements

- Project traffic
  - 20-year design-lane ESALs
- Project pavement cross-section
  - Layer thicknesses
- Pavement layer asphalt binder selection or project location

Goals of Laboratory Compaction

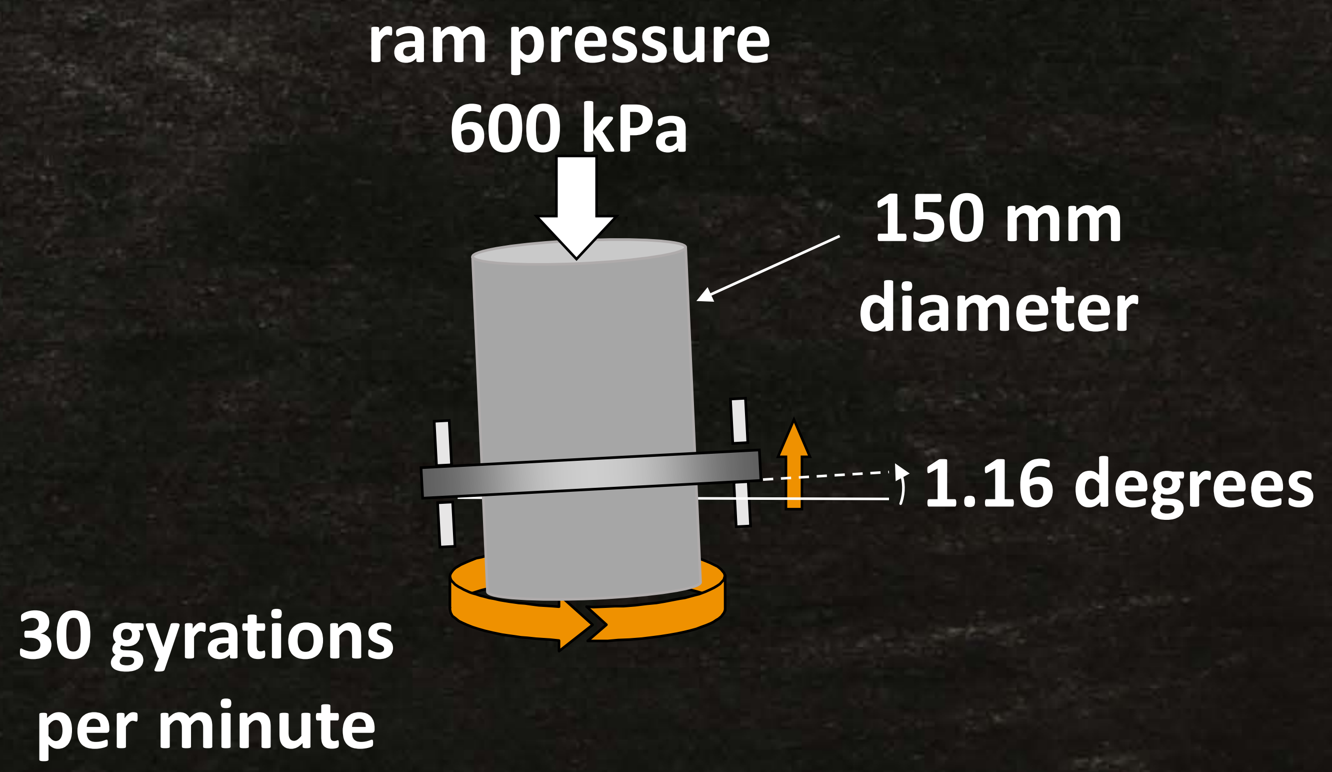
- Simulate field densification
  - Construction
  - Traffic – affected by binder grade and pavement temperature
- Assess the mixture's compactability

In-Place HMA Density Change over Time/Traffic



Superpave Gyratory Compactor

- 150 mm diameter mold accommodates up to 37.5 mm NMAS
- Heights recorded through compaction process



SGC Makes & Models

Troxler 4141 | Troxler 5850 | Pine AFGB1 | Pine AFG2 | IPC Servopac

Gyratory Compaction

- Density of mixtures is evaluated at three points:
  1. $N_{initial}$
  2. N_{design}
  3. $N_{maximum}$

N represents numbers of gyrations

- The density at N_{design} ($\%G_{mm}@N_{design}$) is the most important of these three points. It is where volumetric properties are determined.
- The density at $N_{initial}$ $\%G_{mm}@N_{initial}$) is used to assess the strength of the aggregate structure.
- The density at N_{max} ($\%G_{mm}@N_{max}$) is used to determine if the mix may tend to continue to densify under long-term heavy traffic.

Current AASHTO R35 N_{design} Table

Traffic Level Million ESALs	Compaction Level $N_{initial}$	N_{design}	$N_{maximum}$
< 0.3	6	50	75
0.3 to < 3.0	7	75	115
3.0 to < 30.0	8	100	160
> 30.0	9	125	205

Note: Most states use different N_{design} levels

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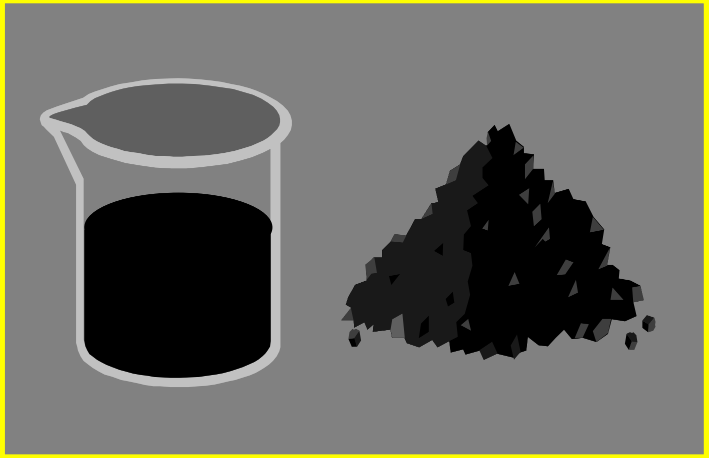
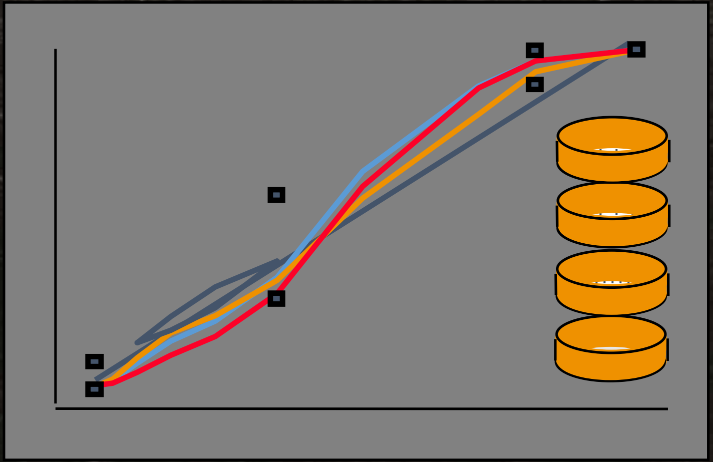
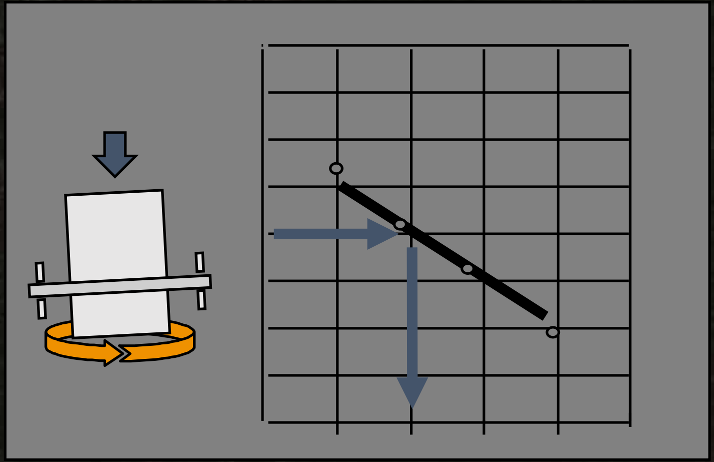
4 Steps of Superpave Mix Design



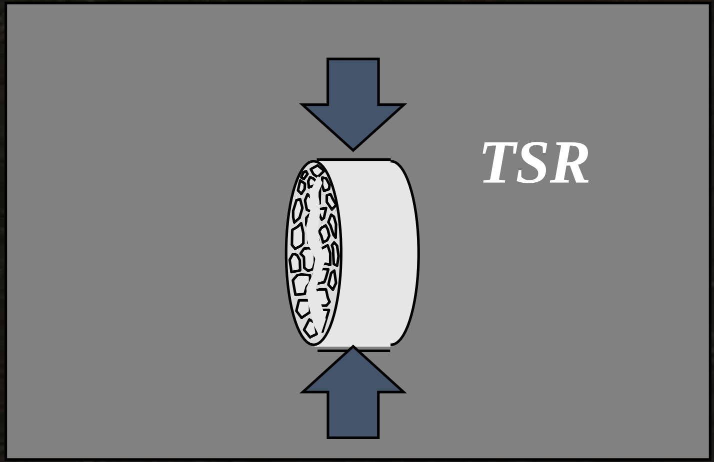
1. Materials selection



2. Design aggregate structure



3. Design binder content



4. Moisture sensitivity

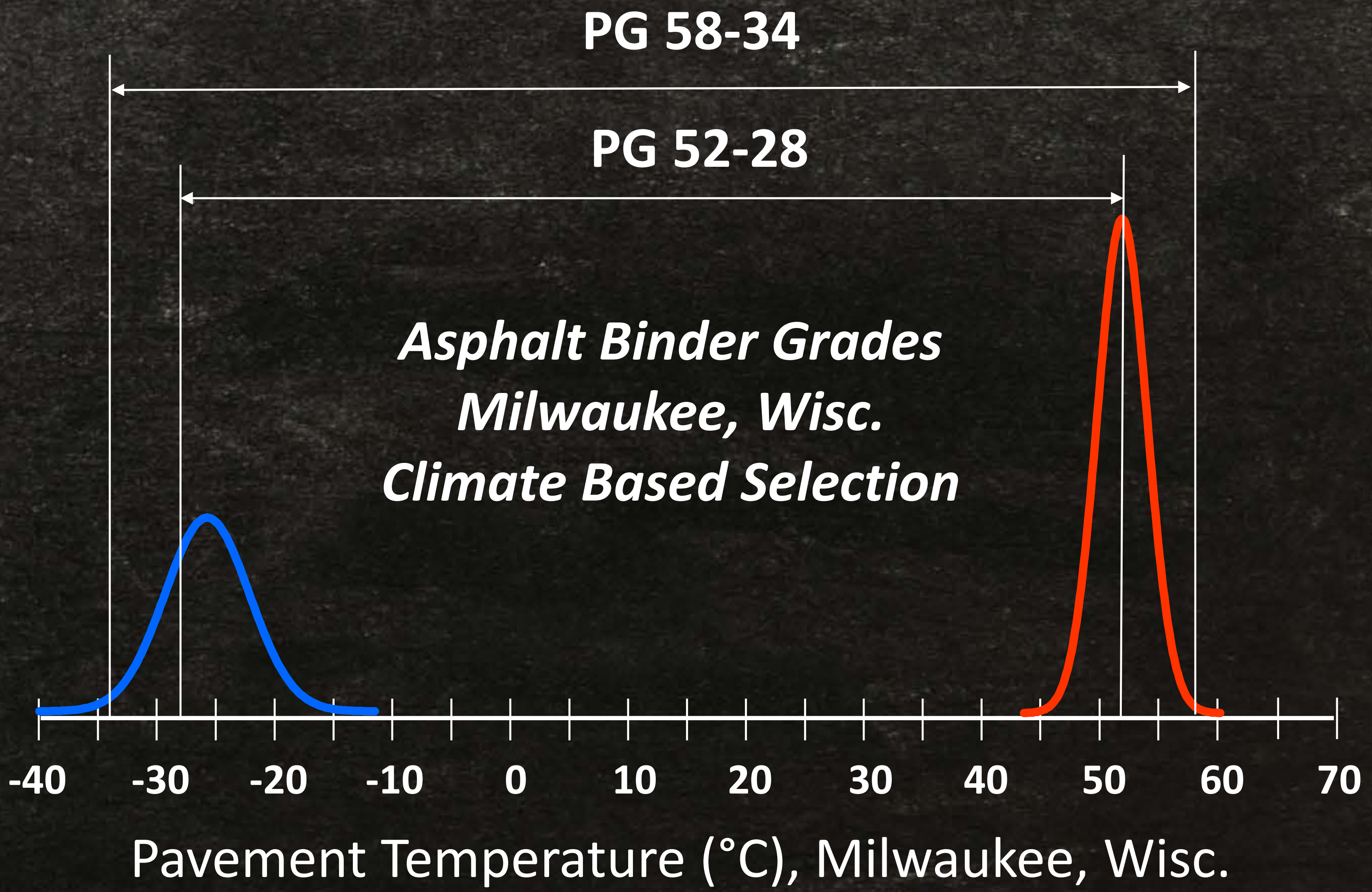
Step 1: Materials Selection

- Binder selection
  - The binder grade is specified in nearly all cases
  - Selecting binder *supplier* usually based on cost
- Aggregates selection
  - Must comply with specified criteria
  - Choice of aggregates usually limited to locally available materials
  - NMAS is typically selected based on layer thickness

Example Project

- Project on I-43
- Milwaukee, Wisconsin
- 18,000,000 ESAL Design
- Asphalt overlay - 120 mm total thickness
  - 40 mm - wearing course (12.5 mm NMAS)
  - 80 mm - intermediate course (19.0 mm NMAS)

Example mix design



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Binder Selection: Milwaukee, Wisc.

PG 52-28 **PG 58-34**

Reliability (%)	50	74.5	99.9	99.6

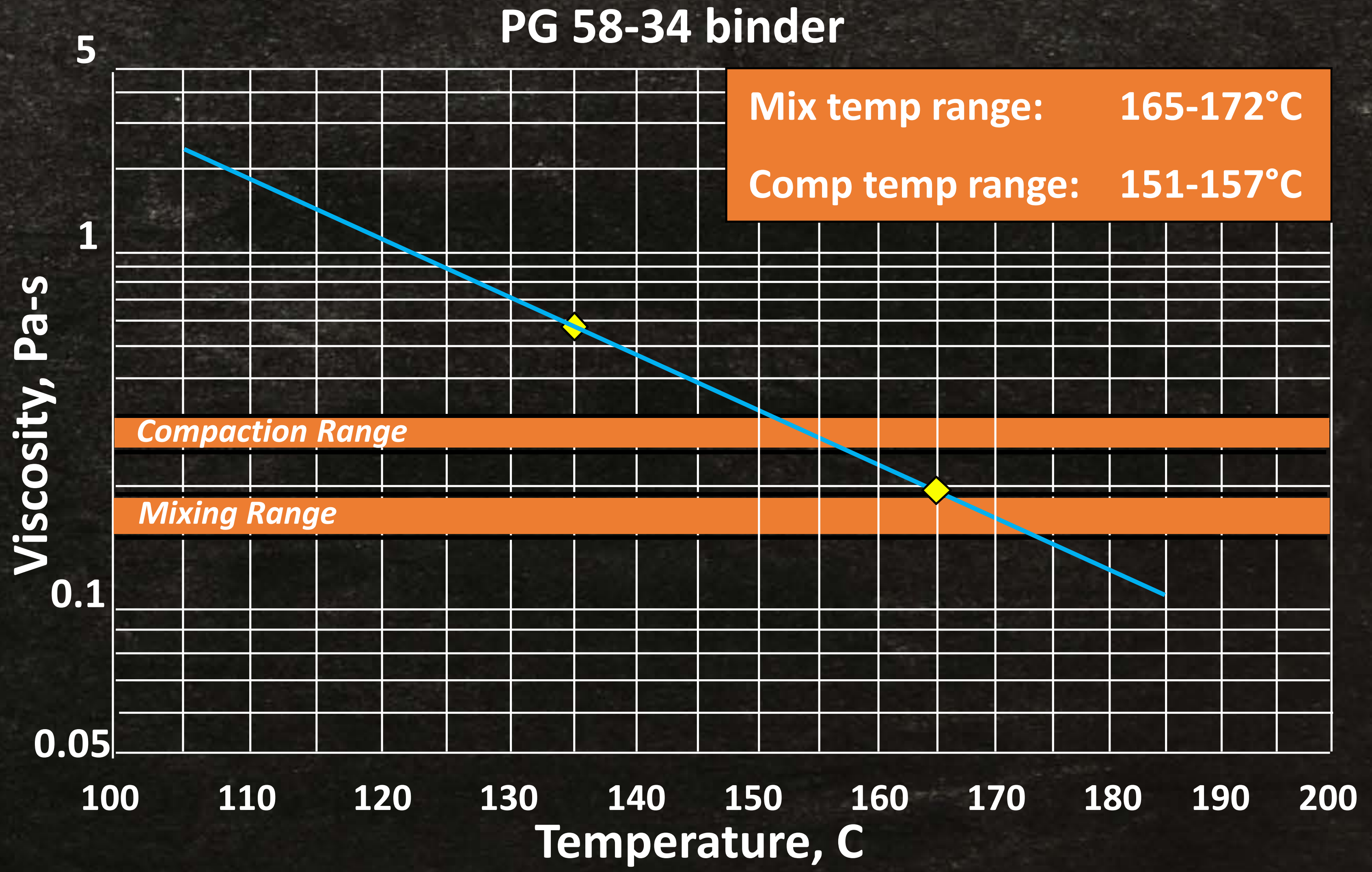
Selected PG 58-34

http://www.tfhrc.gov/pavement/ltpp/ltppbind.htm

Adjusting the virgin binder grade

- Increase the high PG by one grade when:
  - traffic speed is slow e.g. between 20 and 70 km/h (12 to 43 mph))
- Increase the high PG by two grades when:
  - traffic speed is standing (e.g. less than 20 km/h (12 mph))
- Decrease the high and low PG by one grade when:
  - RAP content is more than 25 percent (RAP binder ratio > 0.25)

Mixing and Compaction Temperatures

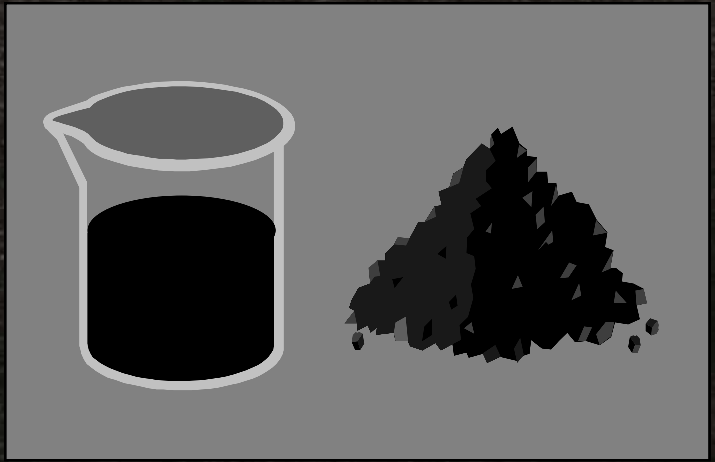


Available Aggregates

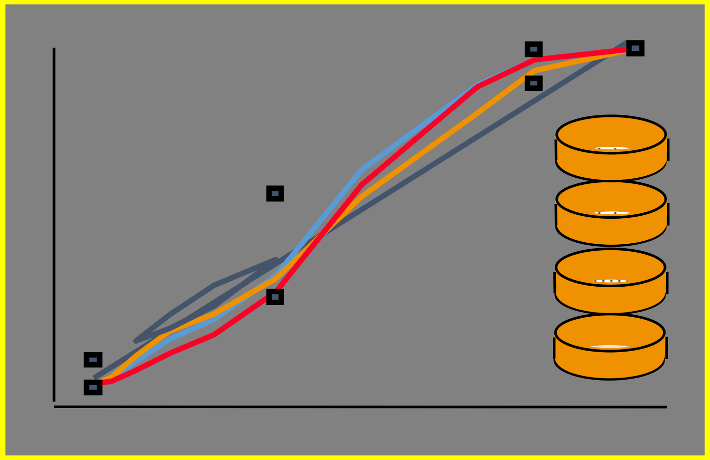
Available stockpiles

- #56
- #67
- #8
- #10
- Natural sand

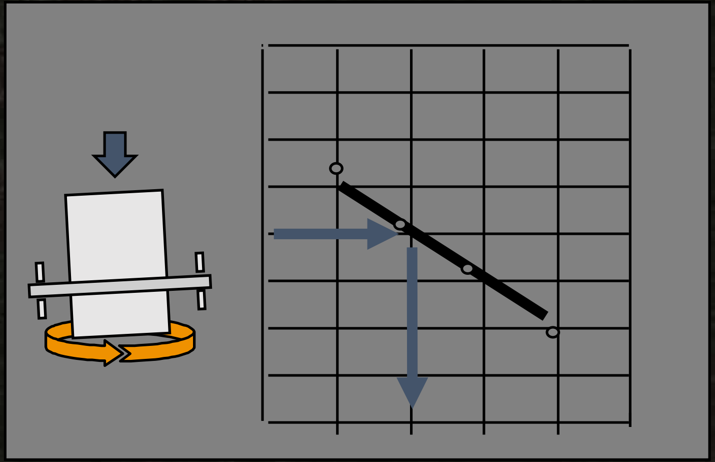
4 Steps of Superpave Mix Design



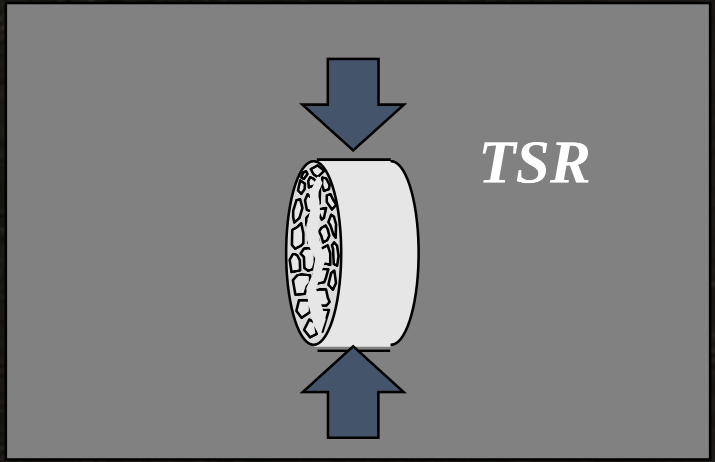
1. Materials selection



2. Design aggregate structure



3. Design binder content



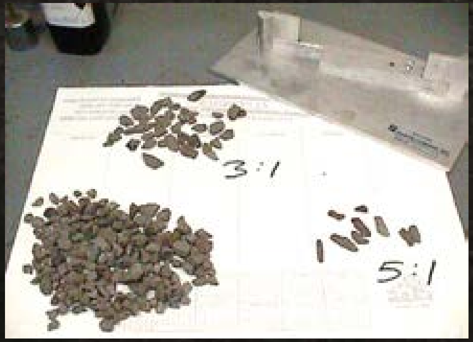
4. Moisture sensitivity

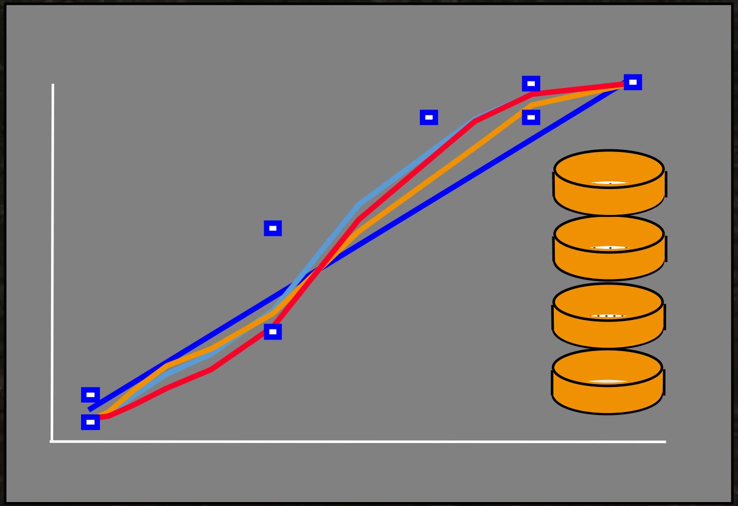
Step 2: Design the Aggregate Structure

- Establish trial blends
- Check aggregate consensus properties
- Compact specimens
- Evaluate volumetric properties of trial blends
- Select design aggregate structure

Consensus Aggregate Properties

See criteria in AASHTO M 323





Consensus Aggregate Requirements

Design EASLs Millions	Fracture Faces Coarse Agg. Min. %		Uncomp. Voids Fine Agg. Min. %		Sand Equiv. Min. %	Flat & Elong. Max. %
	Depth from Surface		Depth from Surface			
	≤ 100 mm	> 100 mm	≤ 100 mm	> 100 mm		
< 0.3	55/–	–/–	–	–	40	–
0.3 to <3	75/–	50/–	40	40	40	10
3 to <10	85/80	60/–	45	40	45	10
10 to <30	95/90	80/75	45	40	45	10
≥30	100/100	100/100	45	45	50	10

one face/two faces

All consensus aggregate requirements apply to the blend, not the individual components.

See M323 for other notes

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Example Coarse Agg. Angularity

TEST RESULTS

Aggregate	1+ Frac Faces	Criterion	2+ Frac Faces	Criterion
#56	92%		88%	
#67	97%	95% min	94%	90% min
#8	99%		95%	

ASTM D 5821 Determining the Percentage of Fractured Particles in Coarse Aggregate

Example Flat & Elongated Particles

TEST RESULTS

Aggregate	%Flat & Elongated	Criterion
#56	0%	
#67	0%	10% max
#8	0%	

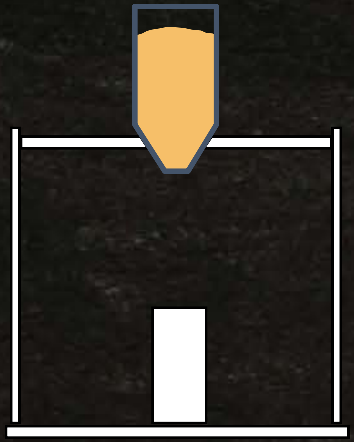
ASTM D 4791 Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate

Example Fine Aggregate Angularity

TEST RESULTS

Aggregate	%Uncomp. Voids	Criterion
#10	48%	45% min
Natural sand	43%	

AASHTO T 304 Uncompacted
Void Content of Fine Aggregate

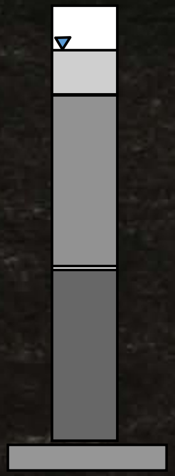


Example Sand Equivalent

TEST RESULTS

Aggregate	Sand Equivalent	Criterion
#10	47	45 min
Nat. sand	70	

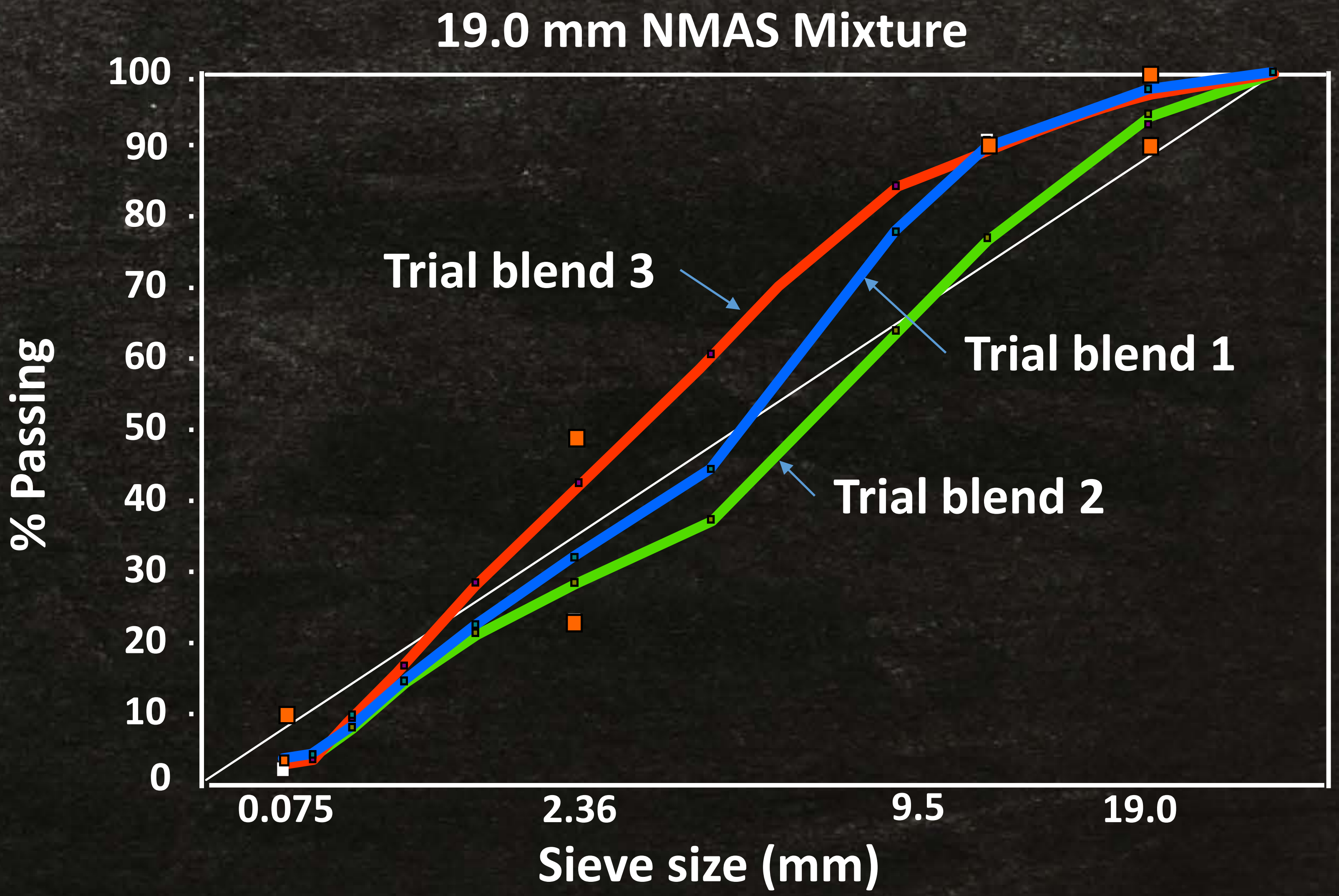
AASHTO T 176 Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test



Example Trial Blends

	Trial blend 1	Trial blend 2	Trial blend 3
#56	25%	30%	10%
#67	15%	20%	15%
#8	17%	13%	20%
#10	18%	10%	26%
Nat. sand	10%	12%	14%
RAP	15%	15%	15%

I-43 Trial Blend Gradations



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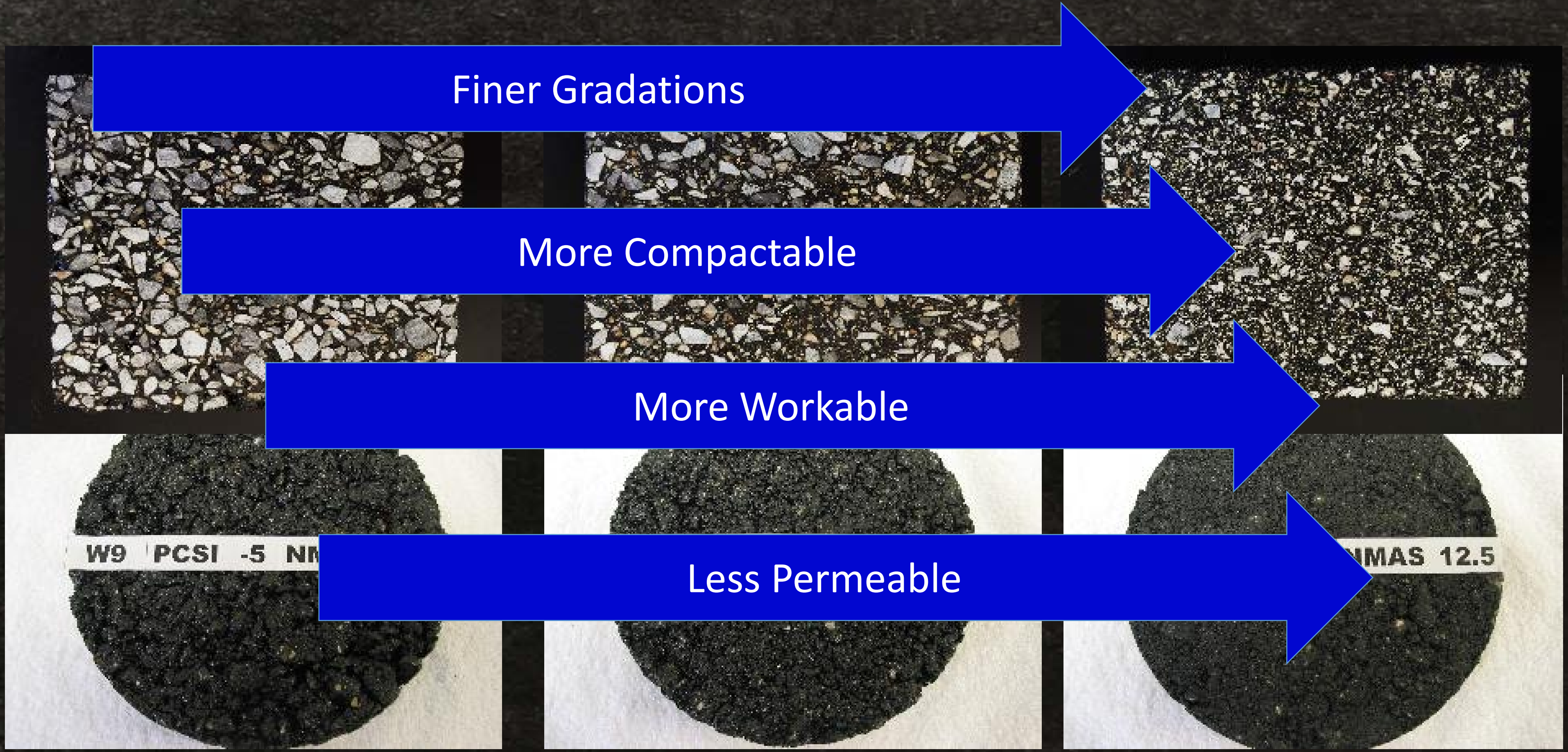
Choosing a Gradation



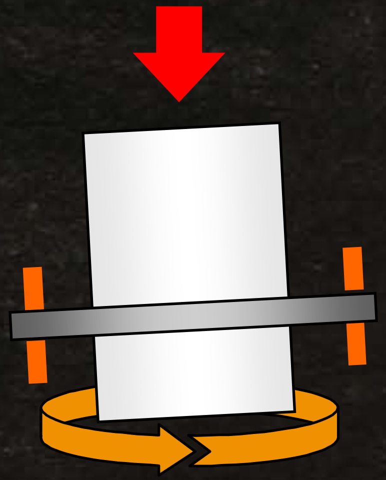
Aggregate Consensus Properties

BLENDED AGGREGATE PROPERTIES ARE DETERMINED

Property	Criteria	Blend 1	Blend 2	Blend 3
Coarse Ang.	95%/90% min.	96%/92%	95%/92%	97%/93%
Fine Ang.	45% min.	46%	46%	48%
Flat/Elongated	10% max.	0%	0%	0%
Sand Equiv.	45 min.	59	58	54
Combined G_{sb}	n/a	2.699	2.697	2.701
Combined G_{sa}	n/a	2.768	2.769	2.767

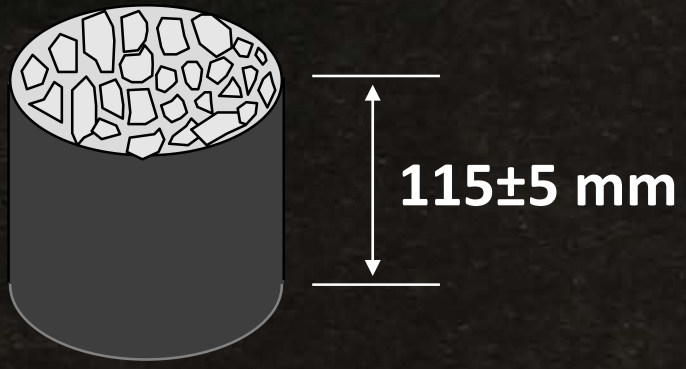
Compact Specimens (Trial Blends)

- Establish a trial asphalt binder content
- Establish trial aggregate weights
- Batch, mix, and compact specimens
- Determine N_{ini} and N_{des}
- Calculate mixture properties



Specimen Preparation

- Specimen height
  - Compacted N_{des} specimens: 115±5 mm (~4700 g)
- Loose specimen for G_{mm} (Rice)
  - Varies with nominal max size
    - 19.0 mm (2500 g)
    - 12.5 mm (1500 g)



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Batching Samples of Trial Blends

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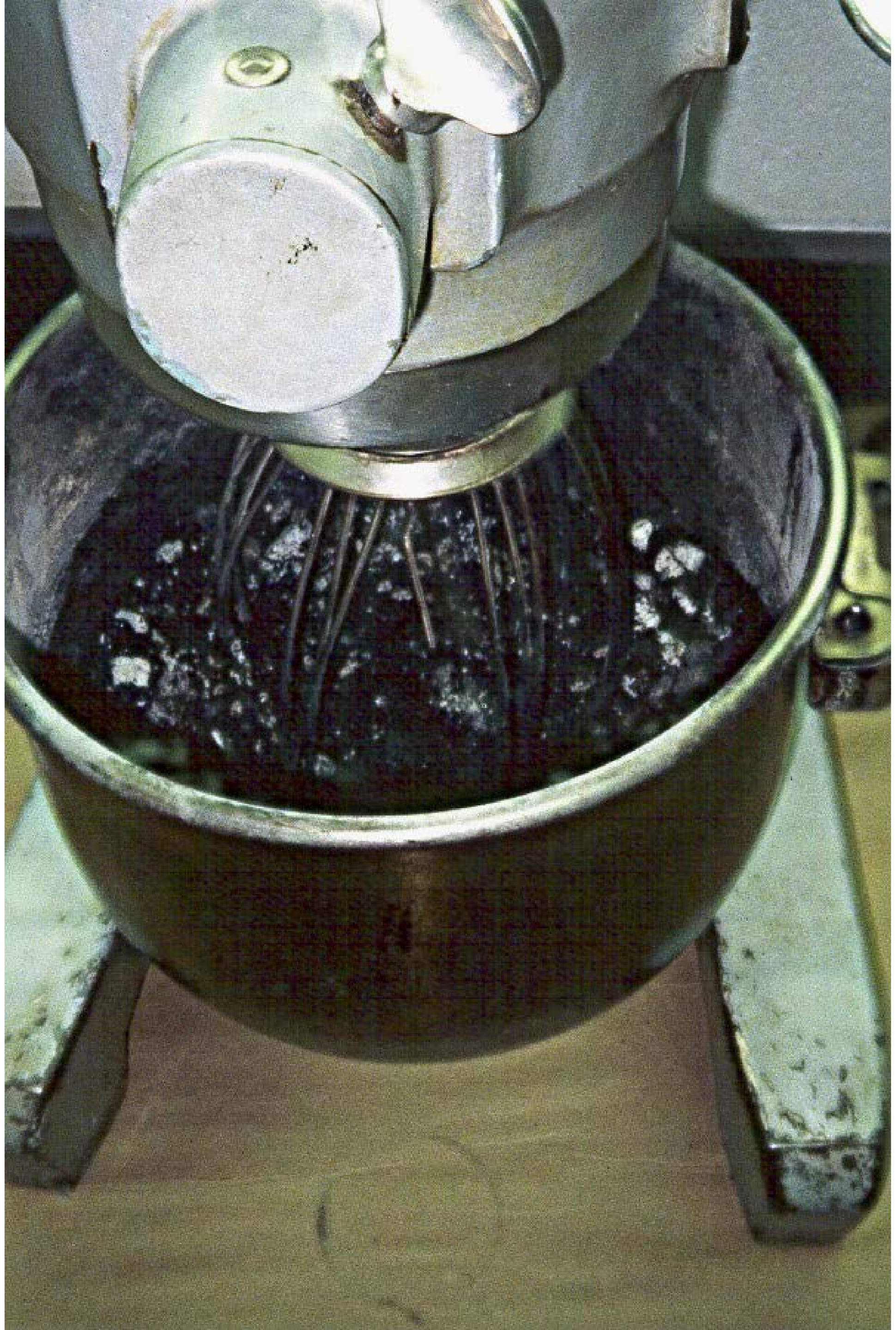
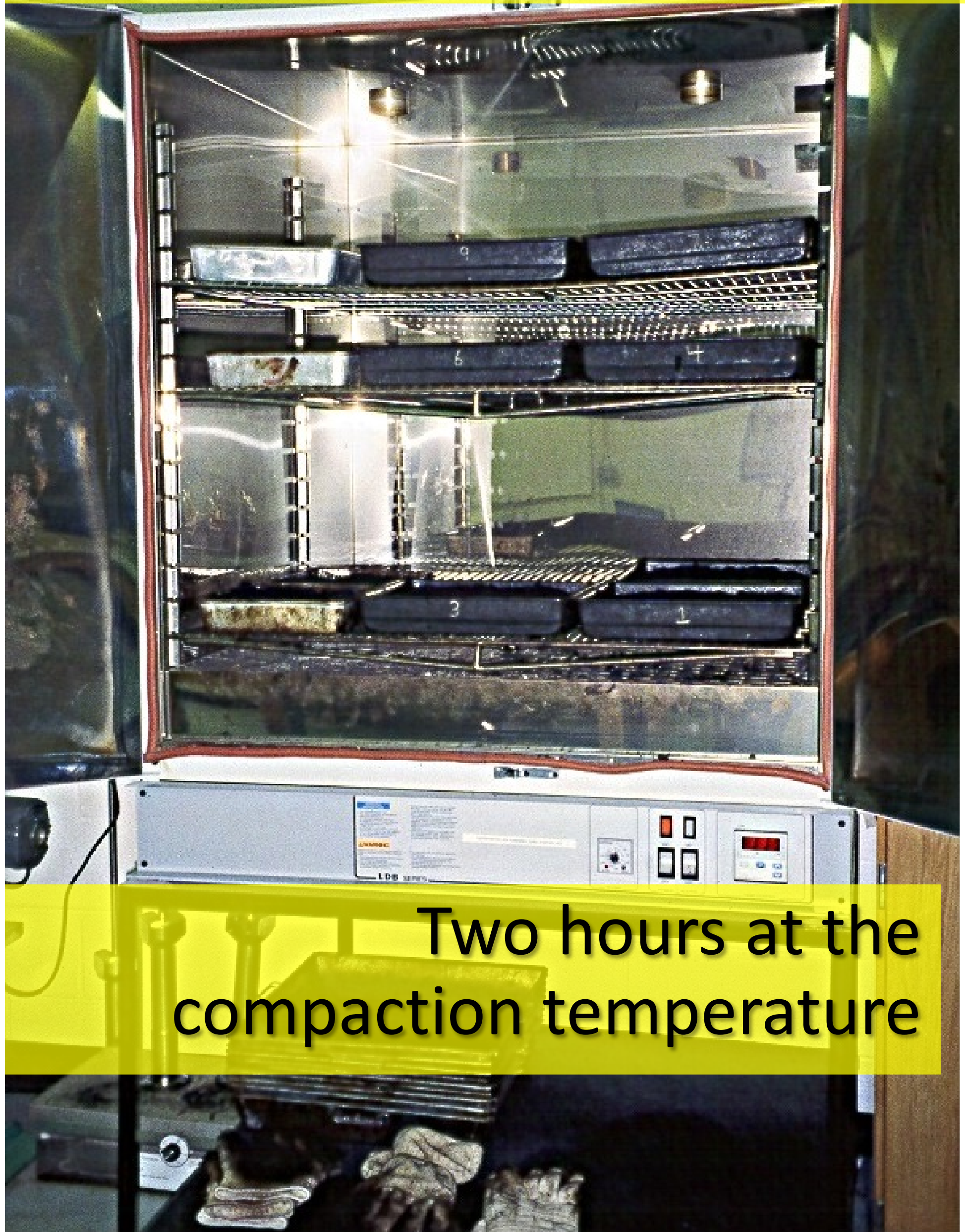
OHAUS
ON/TARE
OFF

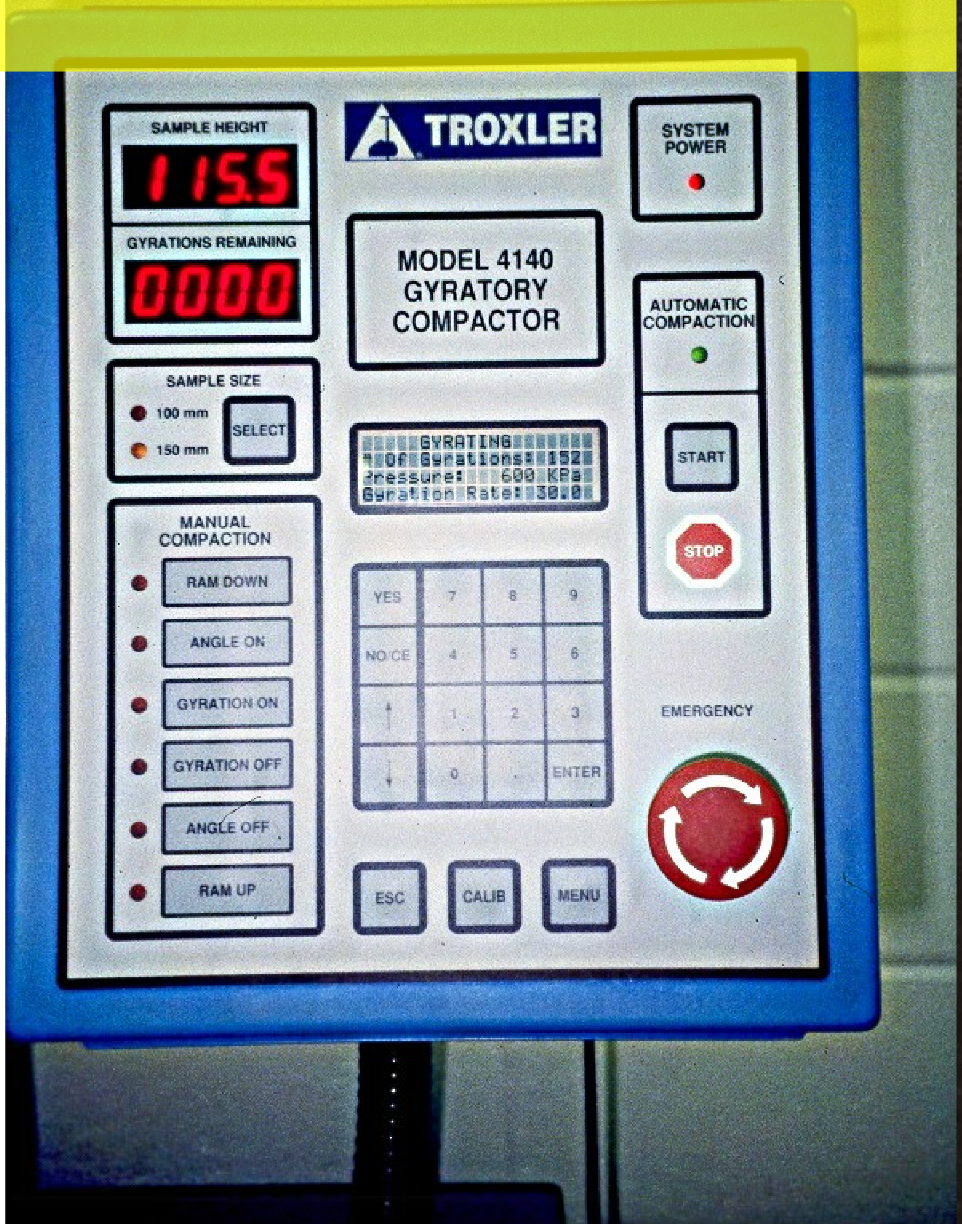


Mix Conditioning



Two hours at the
compaction temperature

Set SGC to Design Number of Gyrations



Current AASHTO N_{design} Table

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	$N_{initial}$	N_{design}	$N_{maximum}$
< 0.3	6	50	75
0.3 to < 3.0	7	75	115
3.0 to < 30.0	8	100	160
> 30.0	9	125	205

Note: Most states use different N_{design} levels

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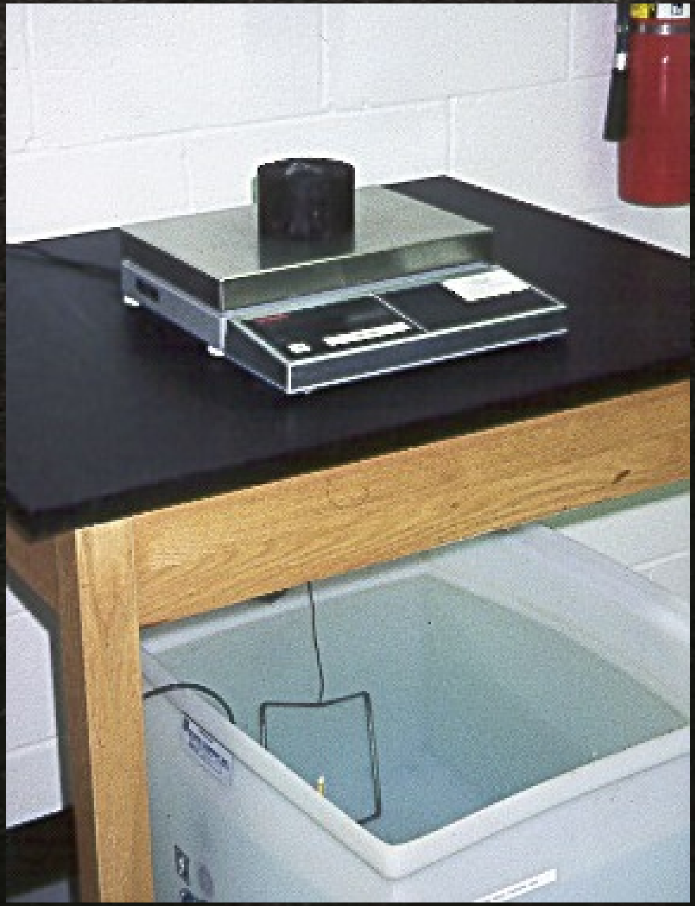
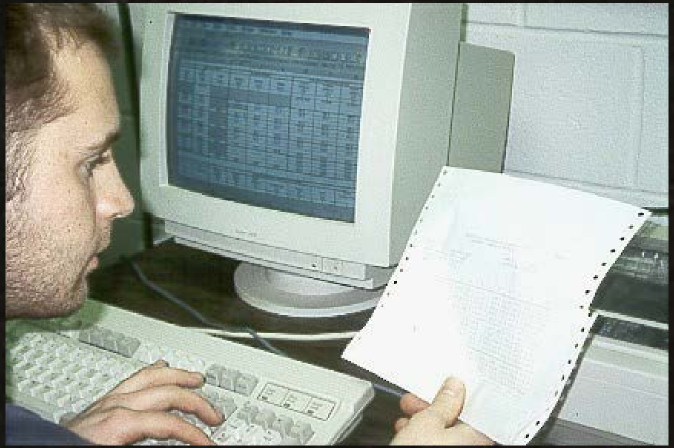
Compact samples, then extrude immediately

Remove paper immediately and label samples

Measure G_{mb}, G_{mm} and Calculate Volumetric Properties





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Superpave Mixture Requirements

- Mixture volumetric properties
  - Air voids
  - Voids in the mineral aggregate (VMA)
  - Voids filled with asphalt (VFA)
- Dust to Binder Ratio
- $\%G_{mm}$ @ N_{ini}

Air Voids (V_a)

Calculated using bulk specific gravity (G_{mb}) and maximum specific gravity (G_{mm}) of the mix

$$\text{Air voids } (V_a) = 100 \times \left(\frac{G_{mm} - G_{mb}}{G_{mm}} \right)$$

$$\%G_{mm} = 100 - V_a$$

Voids in Mineral Aggregate (VMA)

$$VMA = 100 - \frac{G_{mb}(1-P_b)}{G_{sb}}$$

$$VMA = V_a + V_{be}$$

Vbe = volume of effective binder

It is the most important parameter to ensure mix durability

Voids Filled with Asphalt

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

VFA is the percentage of VMA that is filled with asphalt binder

If Va is fixed at 4.0% and a min. VMA is given, then and the min. VFA is redundant

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Calculation of $\%G_{mm}$ @ N_{ini}

To calculate the %Gmm @ Nini, you need the %Gmm @ Ndes and the heights from the SGC at Ndes and Ninitial

$$\%G_{mm} @ N_{ini} = (\%G_{mm} @ N_{des}) \times \frac{Ht.\ @\ N_{ini}}{Ht.\ @\ N_{des}}$$

Superpave Volumetric Criteria

AASHTO M323

Traffic Million ESALs	SGC Compaction % of G_{mm}			VMA (%)	VFA (%)	Dust to Binder Ratio
	N_{ini}	N_{des}	N_{max}			
< 0.3	≤ 91.5				70-80	
< 3	≤ 90.5	= 96.0	≤98.0	see next slide	65-78	0.6 to 1.2
> 3	≤ 89.5				65-75	

Nmax is not evaluated for the trial blends. It is checked later.

See M323 Table 6 for footnotes.

Superpave VMA Requirements

VOIDS IN THE MINERAL AGGREGATE

Nominal Max Size (mm)	Minimum VMA %
4.75	16.0
9.5	15.0
12.5	14.0
19.0	13.0
25.0	12.0
37.5	11.0

Some agencies set higher VMA criteria

Trial Blend Results

Property	1	2	3
Trial binder content	4.4%	4.4%	4.4%
$\%G_{mm}$ @ N_{des}	96.2%	95.7%	95.2%
$\%G_{mm}$ @ N_{ini}	87.1%	85.6%	86.3%
%Air voids	3.8%	4.3%	4.8%
%VMA	12.7%	13.0%	13.5%
%VFA	68.5%	69.2%	70.1%
Dust/Binder Ratio	0.9	0.8	0.9

Estimating P_b to get 4.0% V_a for the Trial Blends

Determine the difference in avg. air void content at N_{des} (*ΔVa*) for each trial blend from the target of 4.0%:

$$\Delta Va = 4.0 - Va$$

Example (Blend 1) $\Delta Va = 4.0 - 3.8 = 0.2\%$

Estimate the change in binder content *(ΔPb)* needed to change the air void content to 4.0%:

$$\Delta Pb = -0.4 \times \Delta Va$$

Example (Blend 1) $\Delta Pb = -0.4 \times 0.2\% = -0.08\%$

Adjusting the VMA

Estimate the change in VMA

$$\Delta VMA = 0.2 \times \Delta Va \qquad if\ Va_{trial} > 4.0$$

$$\Delta VMA = -0.1 \times \Delta Va \qquad if\ Va_{trial} < 4.0$$

$$VMA_{est} = VMA_{trial} + \Delta VMA$$

Example (Blend 1)

$$\Delta VMA = -0.1 \times 0.2 = -0.02\%$$

$$VMA_{est} = 12.7\% + (-0.02\%) = 12.7\%$$

Adjusting $\%G_{mm}@N_{ini}$

Estimate the change in %Gmm@Nini

$$\%Gmm@Nini_{est} = \%Gmm@Nini_{trial} - \Delta Va$$

Example (Blend 1)

$$\%Gmm@Nini_{est} = 87.1\% - 0.2\% = 86.9\%$$

Adjusting Dust to Binder Ratio

Estimate the change in DP

$Pbe_{est} = Pbe_{trial} + \Delta Pb$

$D/B\ Ratio_{est} = P_{0.075} / Pbe_{est}$

Example (Blend 1)

$Pbe_{est} = 4.4\% + (-0.08\%) = 4.3\%$

$D/B\ Ratio_{est} = P_{0.075} / Pbe_{est} = 3.9/4.3\% = 0.9$

Compare Adjusted Trial Blend Results to Mixture Criteria

Property	1	2	3	Criteria
Trial binder content	4.3%	4.5%	4.7%	
$\%G_{mm}$ @ N_{ini}	86.9%	85.9%	87.1%	< 89%
%Air voids	4.0%	4.0%	4.0%	4.0%
%VMA	12.7%	13.0%	13.3%	≥ 13.0%
%VFA	68.5%	69.2%	70.1%	65-75%
Dust/Binder Ratio	0.9	0.8	0.9	0.6-1.2

Select the Design Aggregate Structure

- What if none of the trial blends are acceptable?
  - Recombine existing aggregates to form additional blends (i.e., blend 4, blend 5, etc.)
  - Add one or more new aggregate materials and make new blends
  - Repeat step 2 of the process

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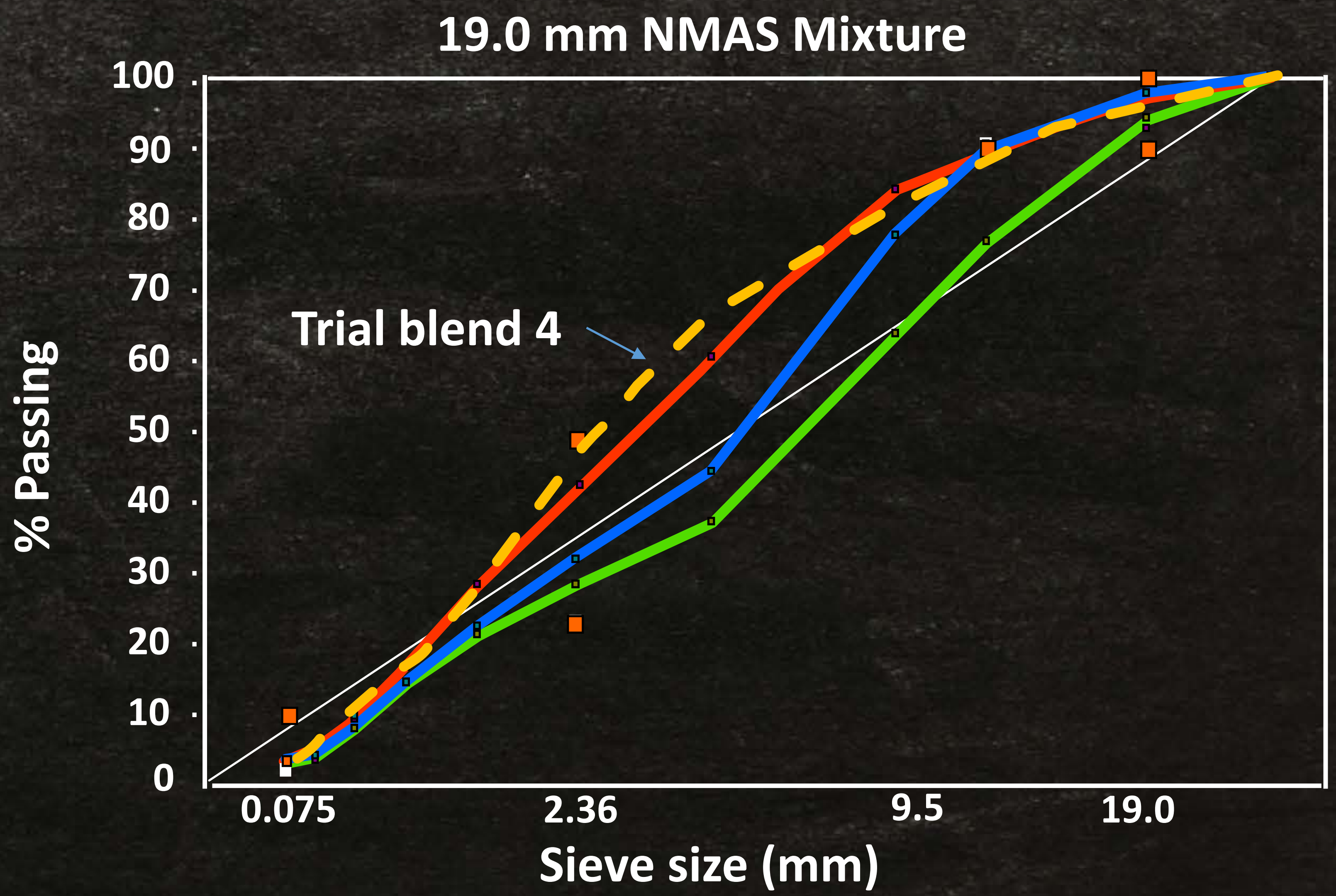
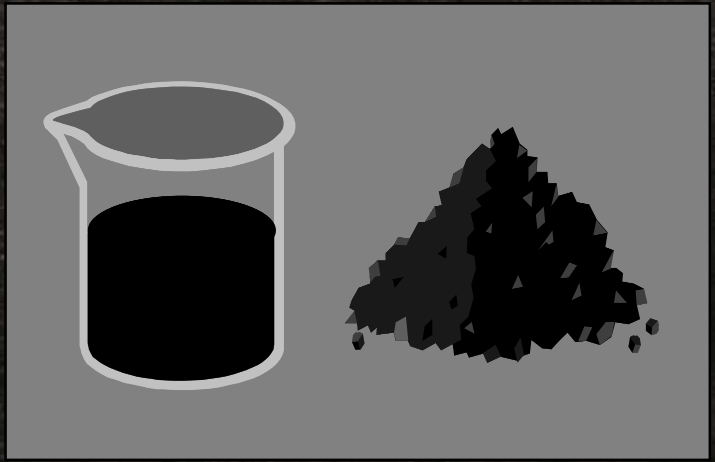
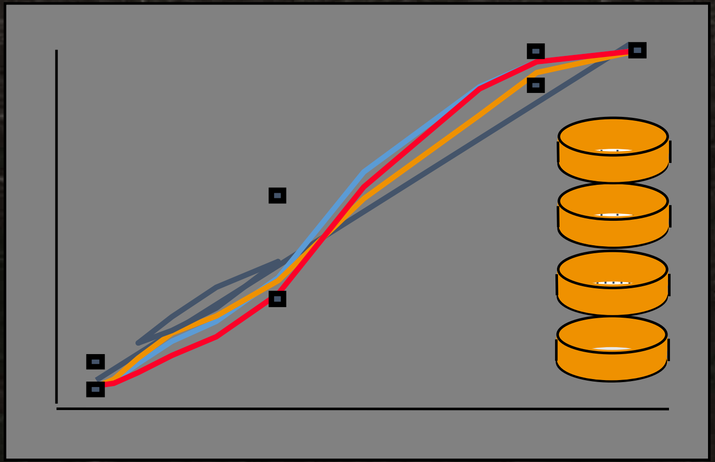
I-43 Trial Blend Gradations



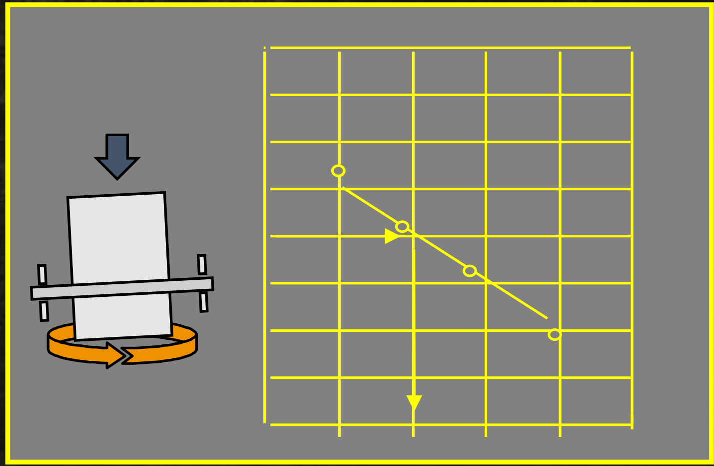
4 Steps of Superpave Mix Design



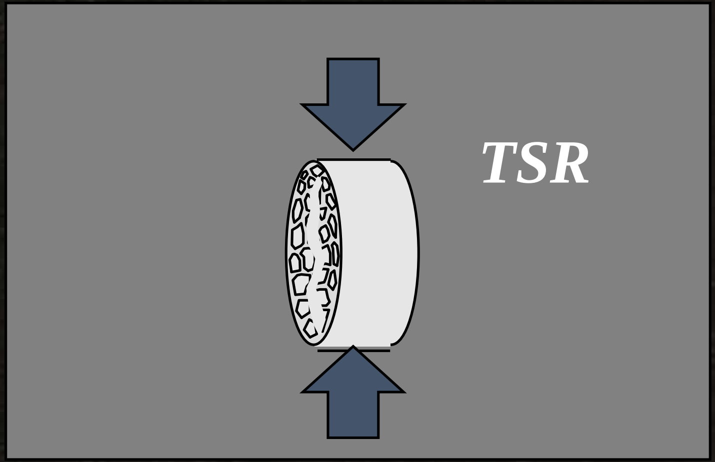
1. Materials selection



2. Design aggregate structure



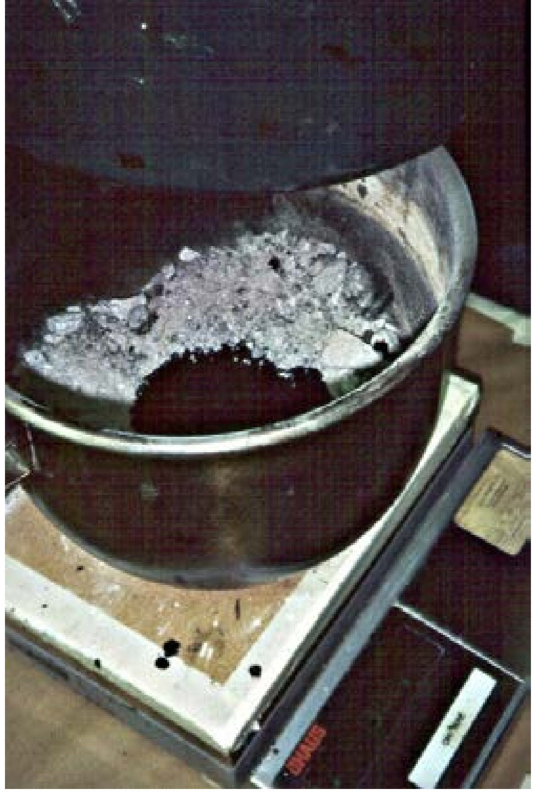
3. Design binder content

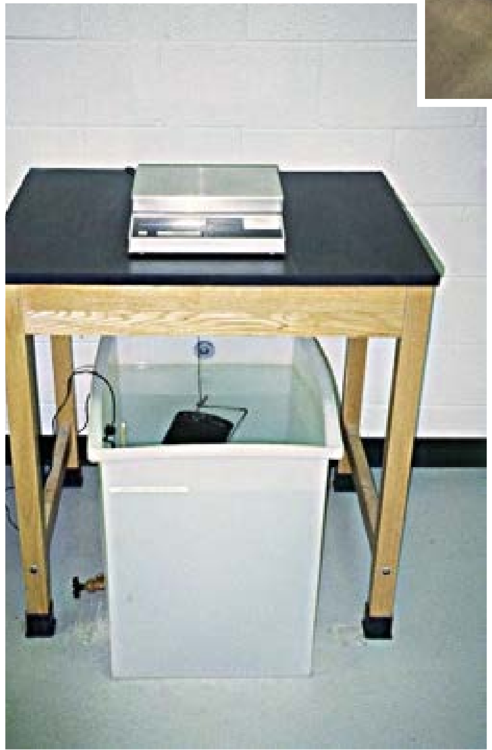


4. Moisture sensitivity

Step 3: Design Binder Content

- The selected trial blend becomes the design aggregate structure
- Batch, mix, and compact more samples with this gradation with four asphalt contents
- Determine volumetric properties
- Select Pb at 4.0% air voids and check other volumetric properties
- Compact an additional set to N_{max} for check





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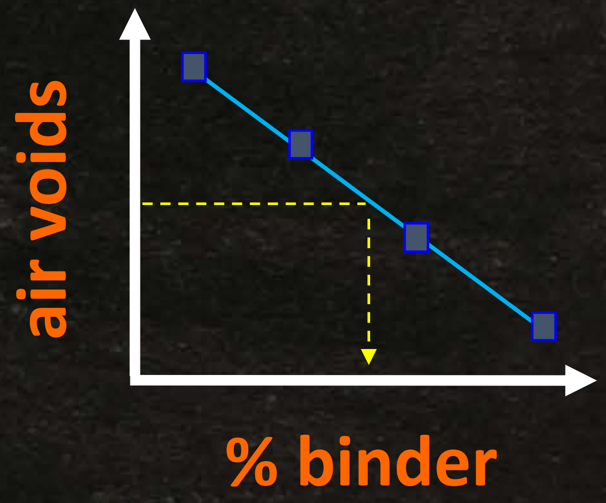
Design Binder Content Samples

Binder content	4.2%	4.7%	5.2%	5.7%
%G_{mm} @ N_{ini}	85.7%	87.1%	87.4%	88.6%
%G_{mm} @ N_{des}	94.6%	96.1%	97.1%	98.2%
%Air voids	5.4%	3.9%	2.9%	1.8%
%VMA	13.3%	13.1%	13.3%	13.5%
%VFA	59.4%	70.2%	78.2%	86.7%
Dust/Binder Ratio	1.0	0.9	0.8	0.7

Mix Air Voids Requirement

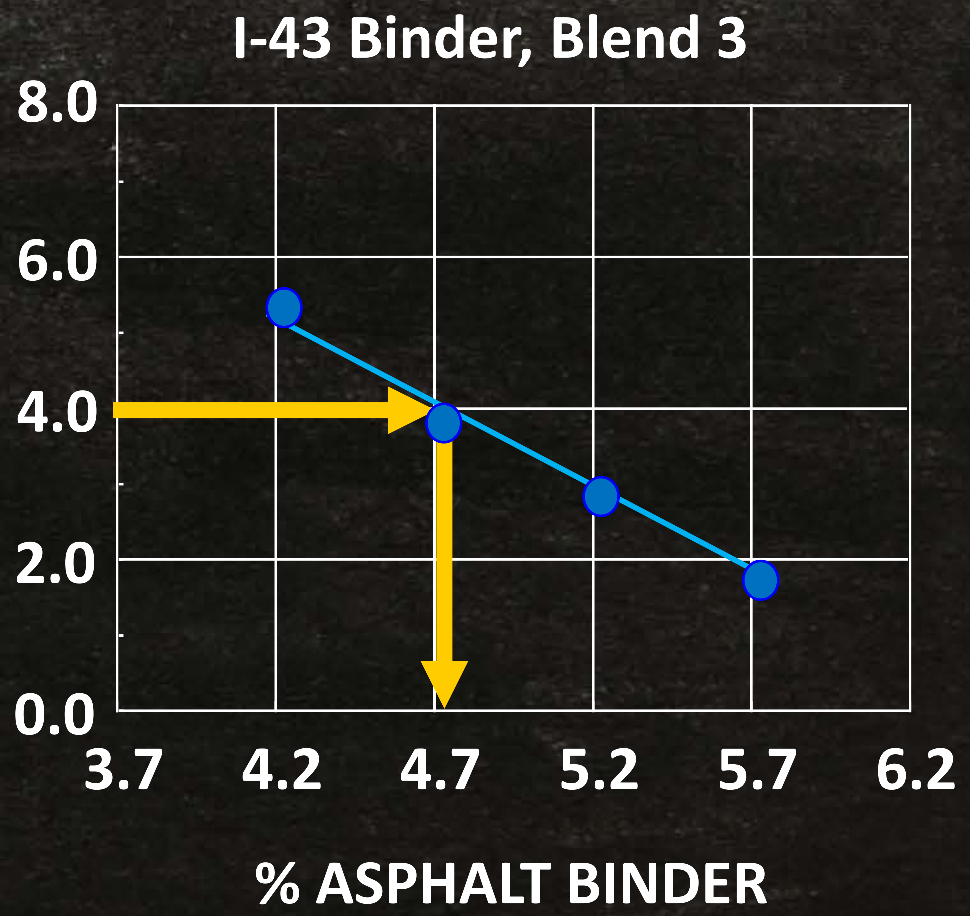
4.0 % at N_{des}
Regardless of the Traffic Level



Some agencies target lower air void contents for some or all mixes

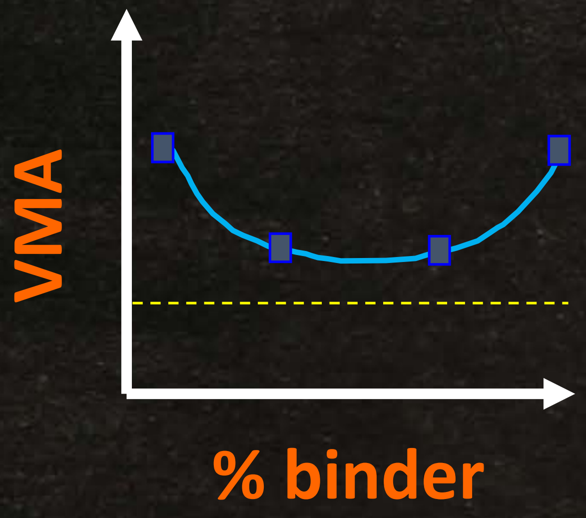
Air Voids: Example Mix Design

Air Voids = 4.0 %



Mix VMA Requirements
Voids in the Mineral Aggregate

Nom Max Size (mm)	Minimum VMA %
4.75	16.0
9.5	15.0
12.5	14.0
19.0	13.0
25.0	12.0
37.5	11.0



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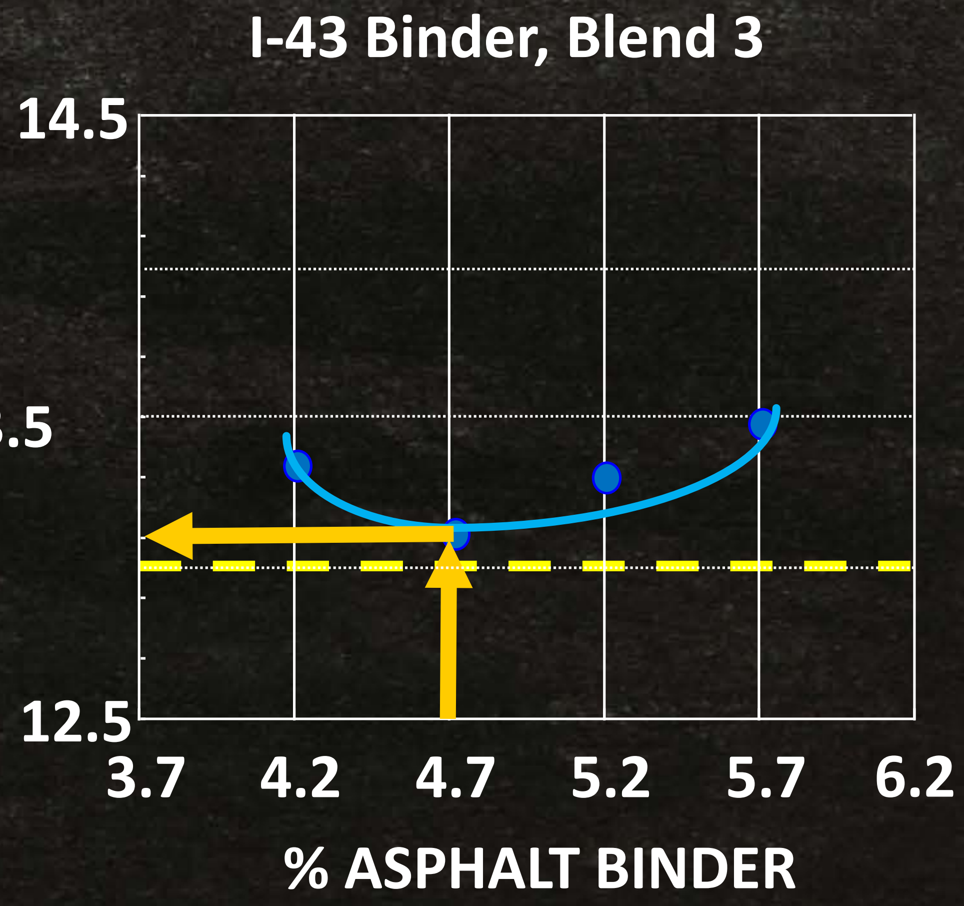
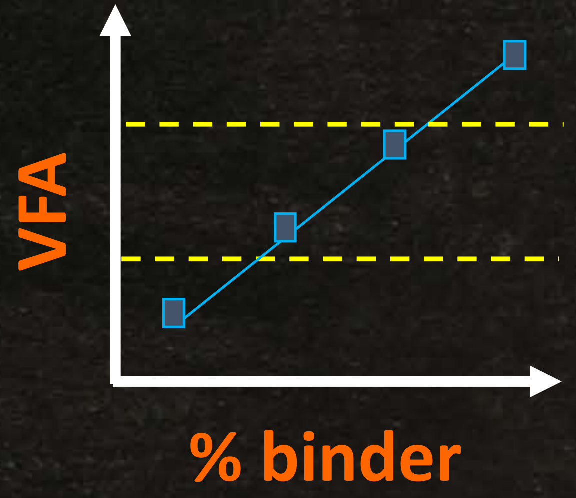
VMA: Example Mix Design

VMA = 13.1%



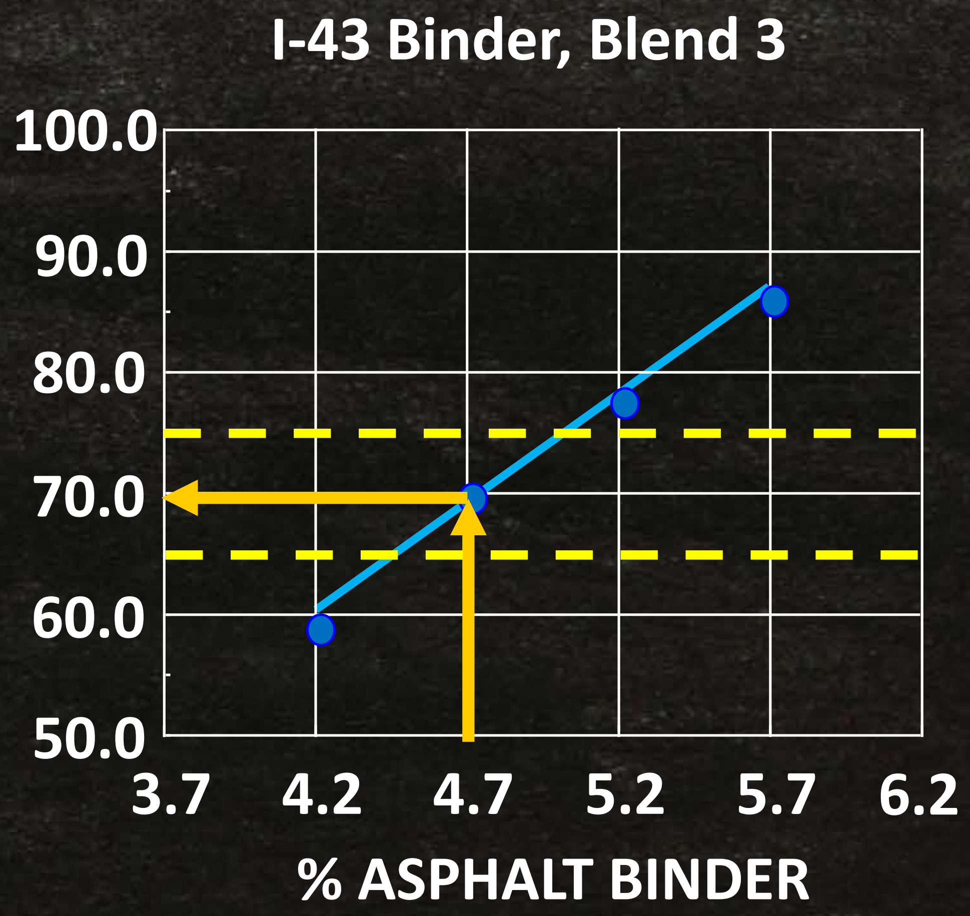
Mix VFA Requirement
Voids Filled with Asphalt

Traffic 10^6 ESALs	Range of VFA %
< 0.3	70 - 80
0.3 to ≤ 3	65 - 78
> 3	65 - 75

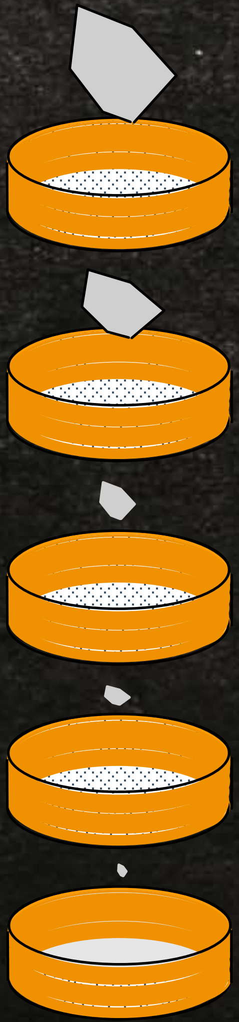


VFA: Example Mix Design

VFA = 70%



Criteria for Dust/Binder Ratio



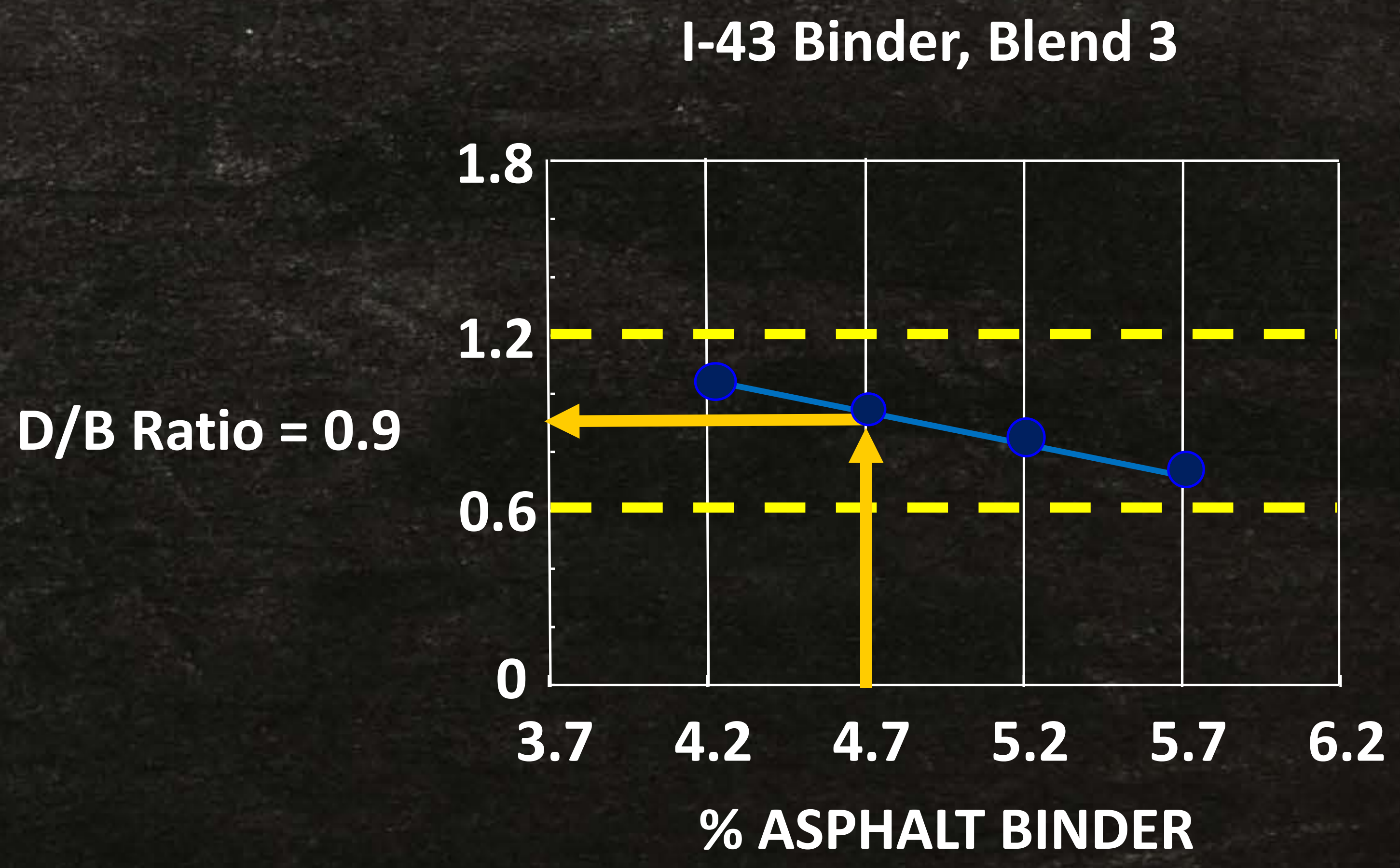
100
100
92
83
65
48
36
22
15
9
4

$$0.6 \leq \frac{\text{\% mass of - 0.075 material}}{\text{\% mass of } \textit{effective} \text{ asphalt}} \leq 1.2$$

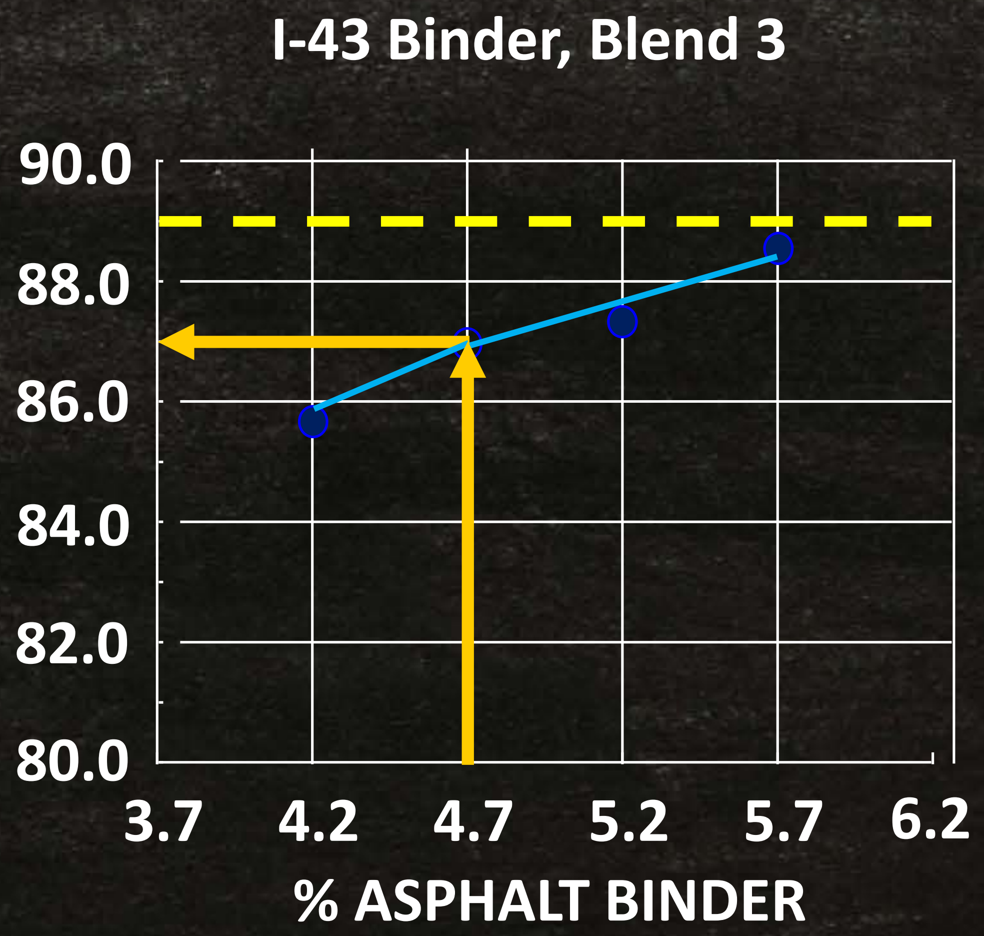
Unabsorbed binder in mix

See M323 Table 6 for exceptions

Dust/Binder Ratio: Example Mix Design



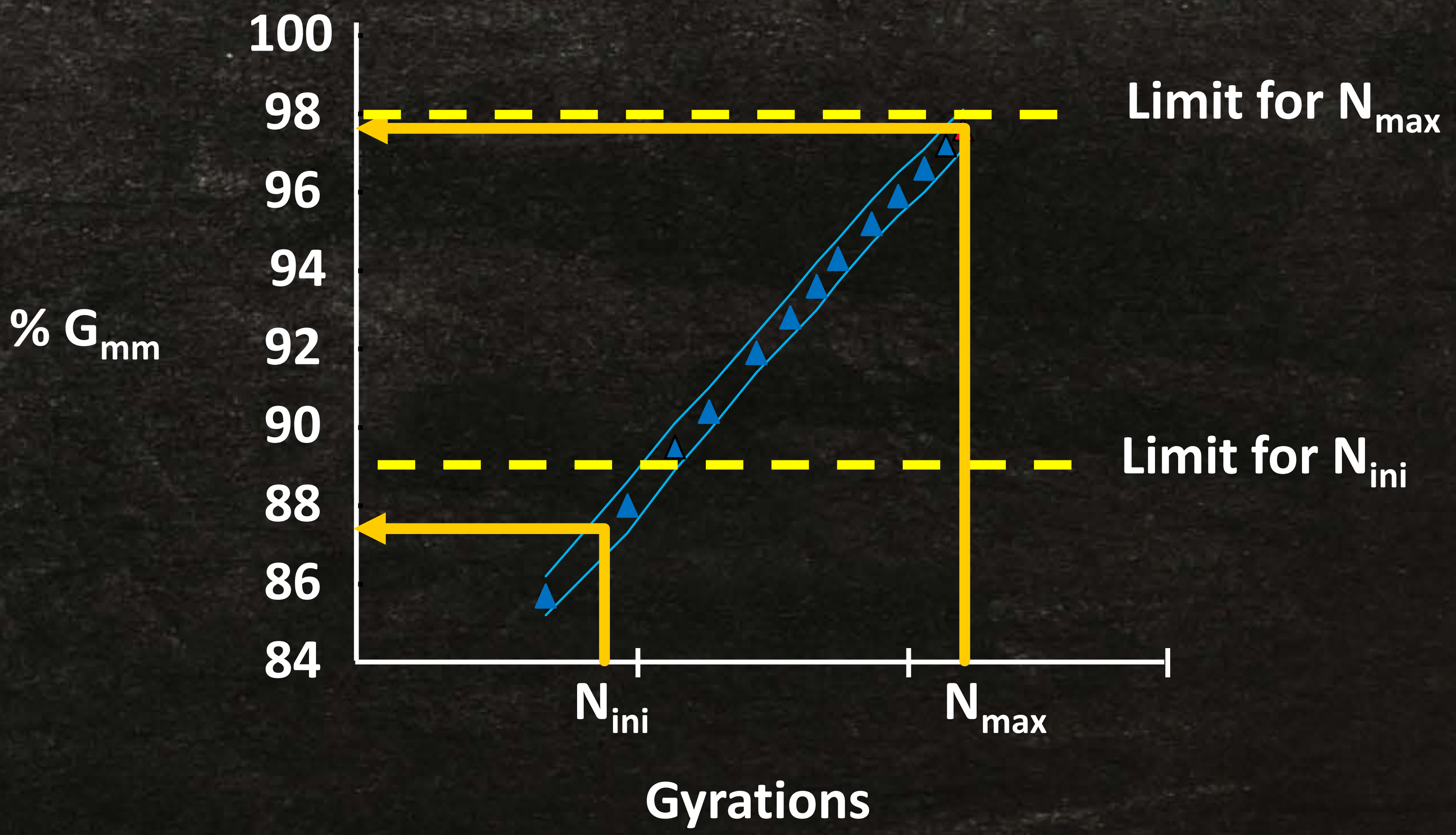
$\%G_{mm}$ @ N_{ini}



$\%G_{mm}$ @ N_{ini}

= 87.1%

Mixture Compaction Checks



Select Design Asphalt Binder Content

SUMMARY OF MIXTURE PROPERTIES @ 4.7% AC

Property	Result	Criteria
%Air voids	4.0%	4.0%
%VMA	13.1%	≥13.0%
%VFA	70%	65-75%
D/A ratio	0.9	0.6-1.2
$\%G_{mm}$ @ N_{ini}	87.1%	<89%
$\%G_{mm}$ @ N_{max}	97.5%	<98%

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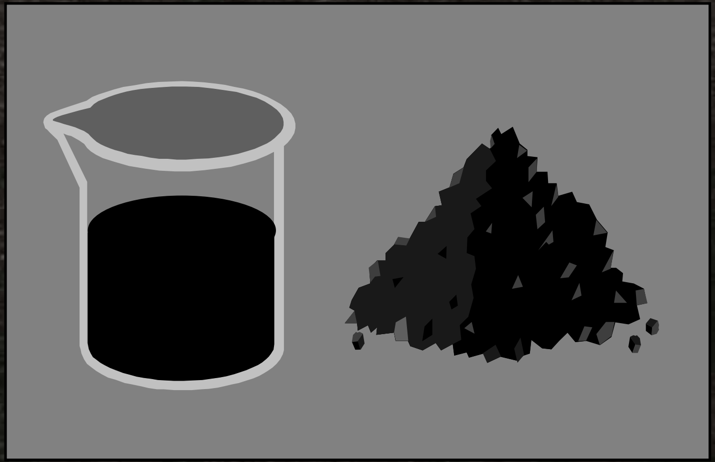
4 Steps of Superpave Mix Design



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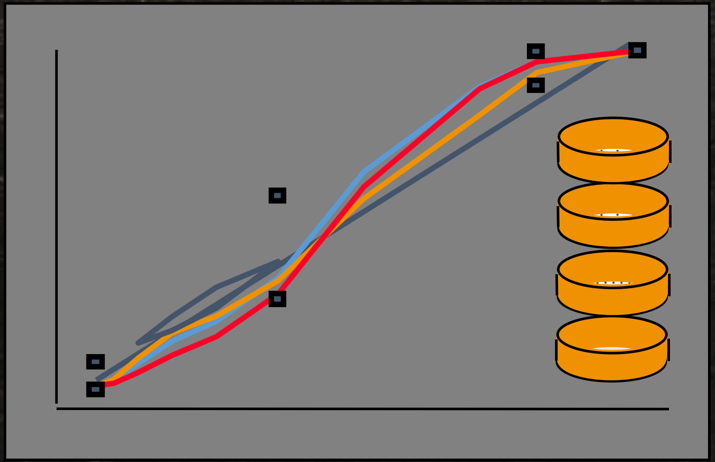

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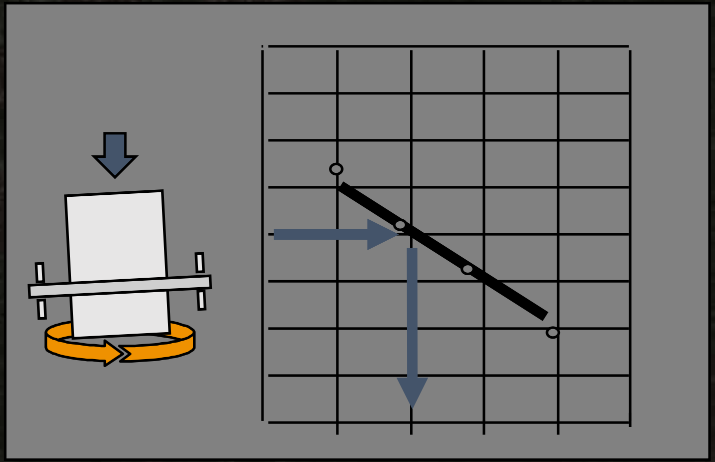
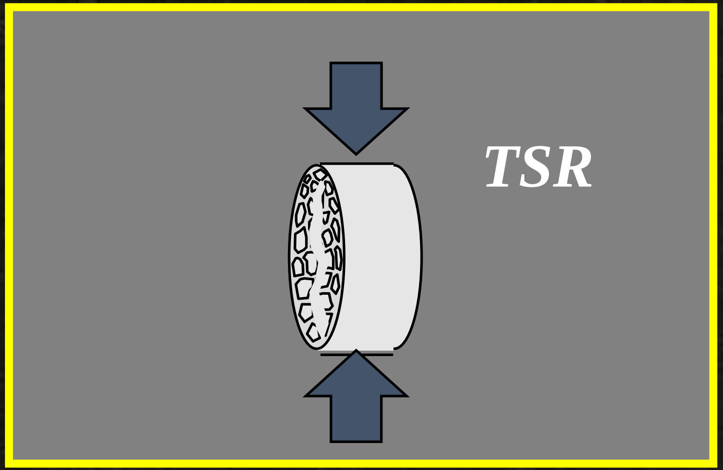


3. Design binder content



4. Moisture sensitivity

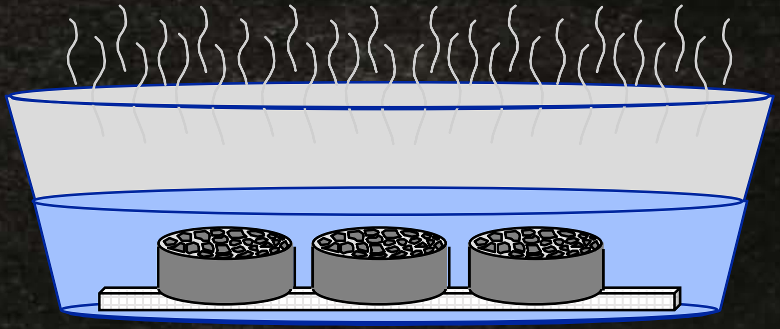
Definition

Moisture susceptibility: loss of adhesion between the aggregate surface and the asphalt binder in the presence of water



Step 4: Moisture Sensitivity
AASHTO T 283

Conducted on the proposed mix design



Three Conditioned Specimens

Three Dry Specimens

80 % minimum

Tensile Strength Ratio

AASHTO T 283 Conditioning

- Conditioning
  - After mixing, cool to room temp. for 2 hrs.
  - Condition loose mix 16 hrs @ 60°C
  - Compact specimens, then set aside for 24 hrs @ 25°C
- Two subsets with equal voids
  - Unconditioned (dry) subset
  - Conditioned subset

7 ± 0.5% air voids

Dry

7 ± 0.5% air voids

70 to 80 % saturation

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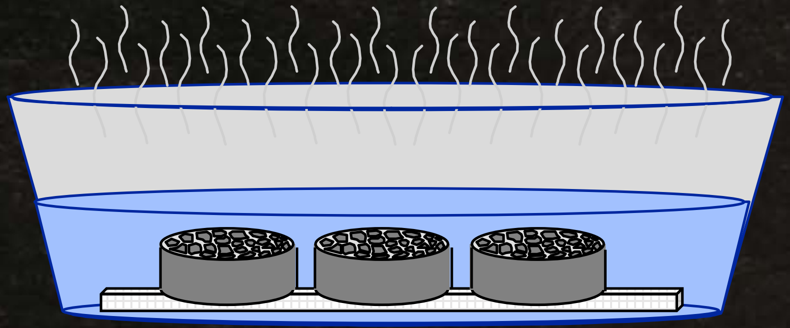
AASHTO T 283 Conditioning

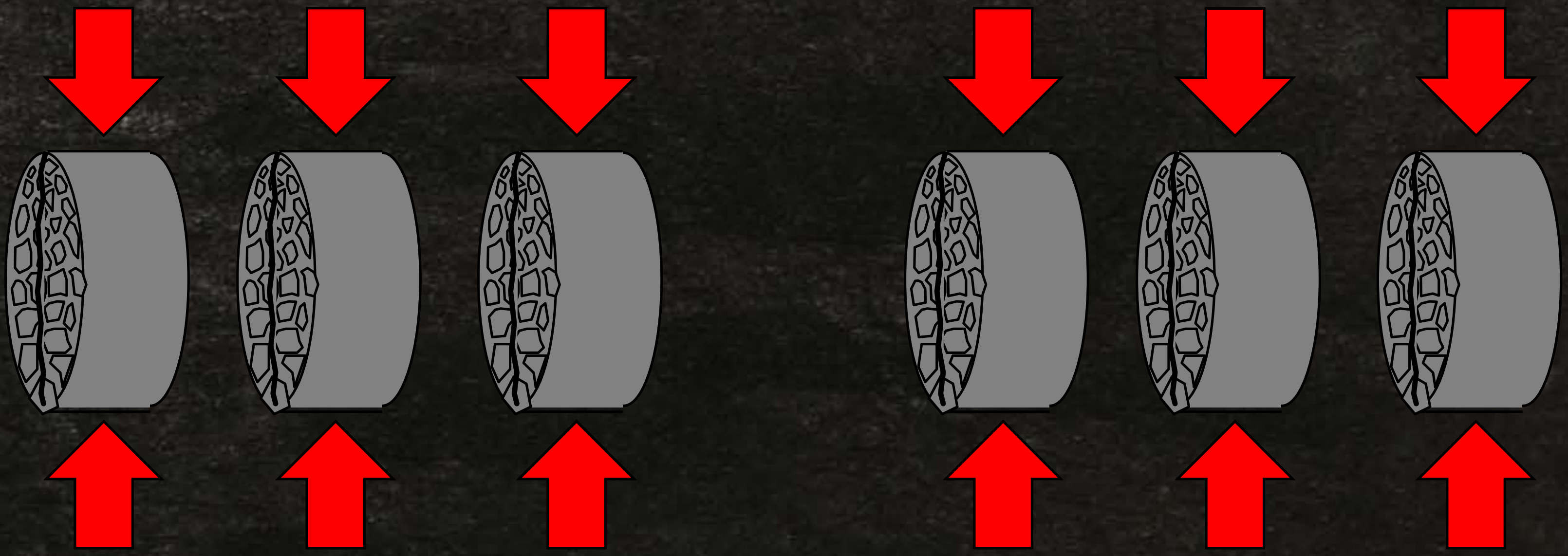
- Freeze-thaw cycle
  - 16 hours @ -18°C

- 24 hour hot water soak
  - 24 hours @ 60°C



AASHTO T 283 Test Procedure

50 mm / min @ 25°C



Average dry tensile strength **Average wet tensile strength**

$$TSR = \frac{\text{wet}}{\text{dry}} \geq 0.80$$

Calculate TSR

$$TSR = \frac{\text{Wet Strength}}{\text{Dry Strength}}$$

$$TSR = \frac{721 \text{ kPa}}{872 \text{ kPa}} = 0.83$$

Criterion is 0.80 minimum.

The mix design exceeds the minimum requirement

Final Asphalt Mix Design
--Job Mix Formula--

Aggregate gradation:

25 mm	100%
19.0 mm	97%
12.5 mm	89%
9.5 mm	77%
4.75 mm	44%
2.36 mm	32%
1.18 mm	22%
0.6 mm	15%
0.3 mm	8%
0.15 mm	5%
0.075 mm	3.9%

Aggregate Blend:

10%	#56 stone
15%	#67 stone
20%	#8 stone
26%	#10 mfg. sand
14%	Nat. Sand
15%	RAP

Asphalt binder:

4.7%	PG 58-34

Mix Design verification during Production

- Mixtures must be verified from plant samples to ensure the mix properties are within the given specification limits.
- Differences in lab prepared mix design and plant produced mix should be expected.
- Take care so that adjustments don't result in a poor quality mix

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Thank you!

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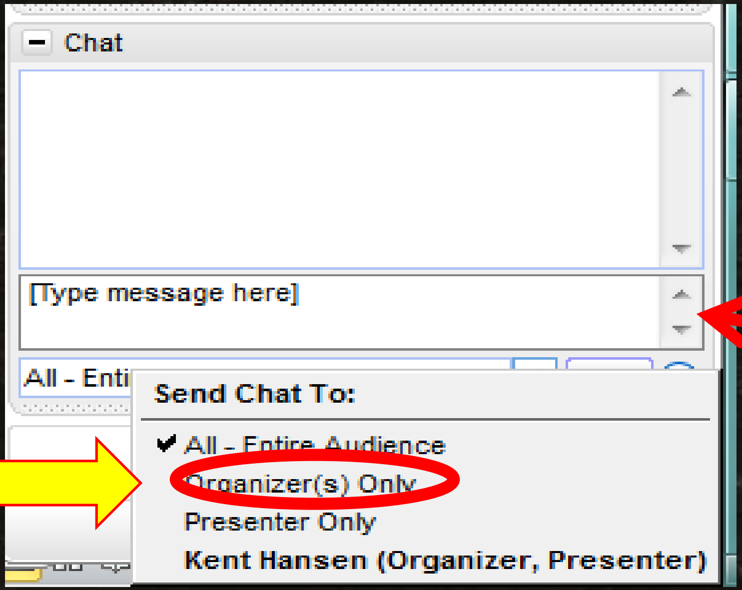
Questions?



Type question here

Select Organizer Only