HMA MIX DESIGN

Mix Design Procedures for NDDOT

ND QC/QA HBP
Mix Design & Production Control

In the past, ND Utilized Two Methods of QC/QA for Hot Mix Asphalt (HMA)

- 409
  - *Marshall* Compaction Hammer Specimen
  - Four Traffic Levels: 27,29,31,33
- 410
  - *Gyratory* Compactor Specimen
  - Six Traffic Levels: FAA40/41/42/43/44/45

ND Utilizes Two Methods of QC/QA for HMA (Con't)

- The predominant specification since 2007 has been the Superpave QC/QA Specification (410)
  - North Dakota's Superpave QC/QA Specification **is now under <u>SECTION 430</u> of the new (2014) Standard Specifications for R&B Construction**
  - Most of the "history" of ND's sand and gravel sources is either in 407/409 Marshall or 408/410 Superpave.

ND Utilizes Two Methods of QC/QA for Asphalt Concrete Pavement (Con't)

- The use of QC/QA Specifications for HMA (Marshall) has been minimal the last five years
  - Marshall Mixes when specified now will be implemented via Special Provision
  - New bid item, "Commercial Grade HMA", Section 430.03 F, has been added in the Standard Specifications for non-QC/QA Superpave mixtures when specified

2014 In Review

- 1,600,699 tons of HBP
  - Class 27 1,872 tons
  - Class 29 54,987 tons
  - Class 31 652 tons
  - Class 33 0 tons
  - Superpave 1,542,616 tons
  - Patching 572 tons

2014 In Review

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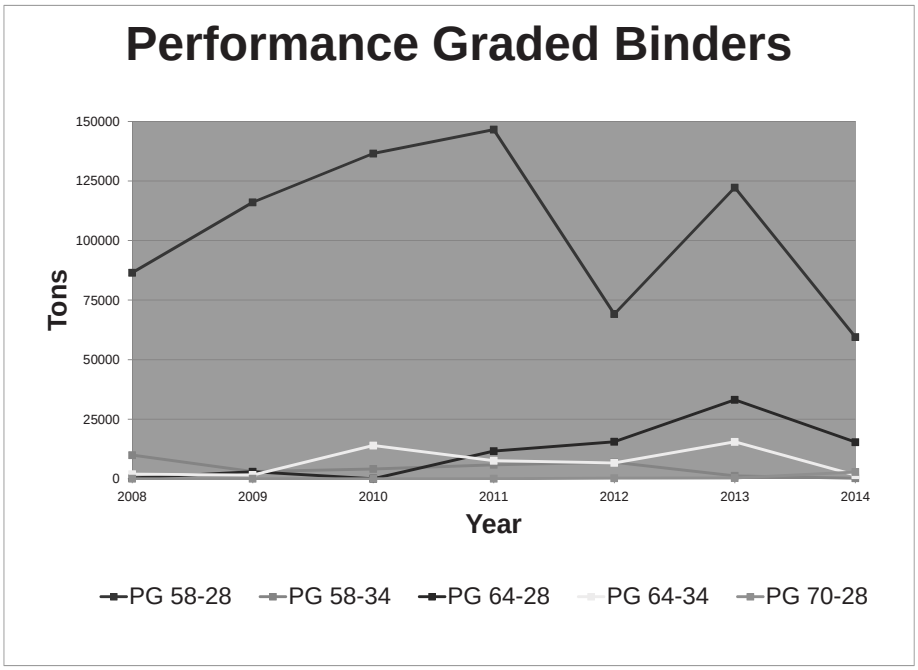
  - Class 31 652 tons
  - Class 33 0 tons
  - Superpave 1,542,616 tons
  - Patching 572 tons
  - Over 90% of Superpave tonnage was FAA 44/FAA 45

2014 In Review

- 79,445 tons of asphalt cement
  - PG 58-28 59,500 tons
  - PG 58-34 203 tons
  - PG 64-28 15,370 tons
  - PG 64-34 1,534 tons
  - PG 70-28 2,838 tons



Perspective

In the United States we have...

- >9,000 Aggregate Sources
- >50 Asphalt Suppliers
- >5 Specifications for Asphalt Cement
  - Pen, AC, AR, PBA, PG
- Numerous Modifiers
- Various Climatic Zones
- Variety of Loading Conditions

Millions of Possible Combinations!

Low volume roads and parking lots

High Volume / Heavy Load

Airports, Ports, Truck Terminals

Introduction

- Each Project is a unique combination:
  - Asphalt
  - Aggregate
  - Within Specific Conditions for Traffic/Climate

Following Proper Mix Design Methods are Critical to Success

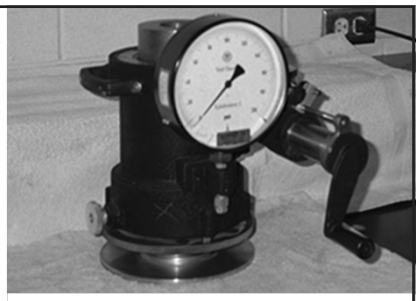
Desirable Properties of HMA

The final goal of mix design is to select a unique asphalt content that will achieve a balance among all the desired properties.

Objectives of Mix Design

- Resistance to Plastic Deformation
  - Should not distort, displace or rut under traffic
- Fatigue Resistance
  - Should not crack under repetitive loading over time
- Resistance to Low Temperature Cracking
- Durability – Film Thickness & Air Voids
- Resistance to Moisture Induced Damage
- Skid Resistance
- Workability

Mix Design Methods



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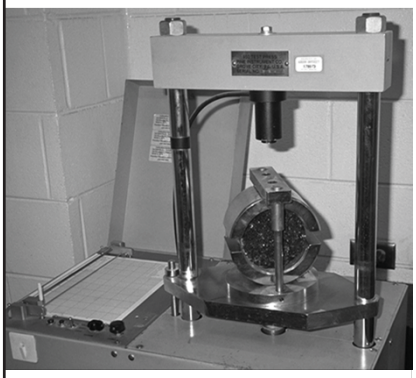
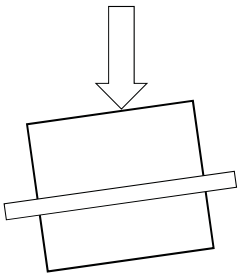


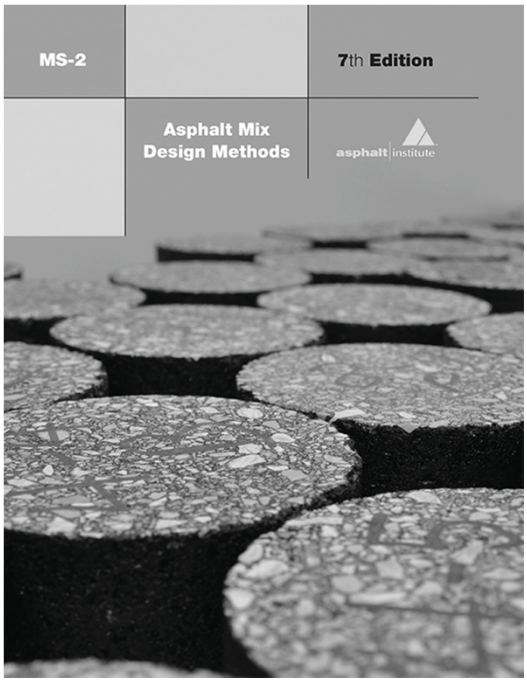
Marshall

Superpave



NDDOT Requirements

- Marshall Method of Mix Design
- Asphalt Institute MS-2
- With Modifications

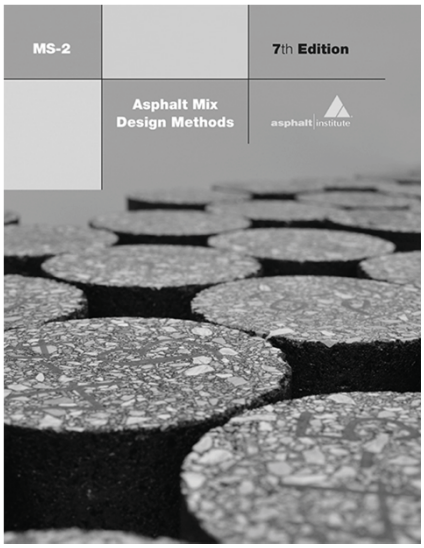


Background

- Developed by Bruce Marshall, MissDOT Bituminous Engineer
- Adopted by US Army Corps of Engineers--WWII
- Used by most states (including SDDOT)
- AASHTO T 245 (SD 316)

Superpave (Gyratory) Mix Design

- Detailed in Asphalt Institute MS-2
- With modifications specified in Special Provisions, Plan Notes and/or Field Sampling & Testing Manual

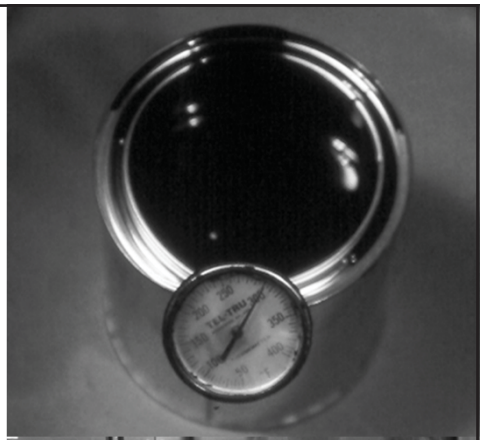


Prepare Samples

- Estimate P_b
- Weigh out asphalt & aggregate for 5 asphalt contents
  - $P_{b\text{-}est}$, +1.0%, +0.5%, -0.5%, -1.0%
  - Three samples for each AC%

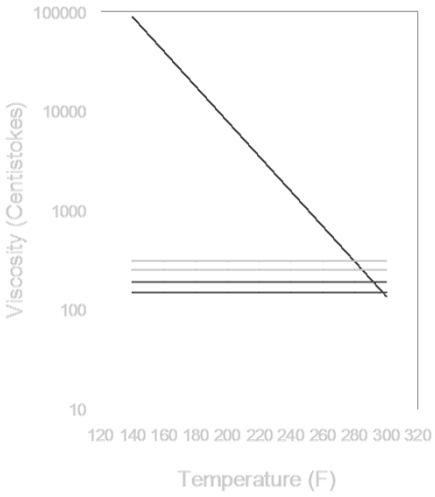
Prepare Samples

- Heat to mixing temperature:
  - asphalt
  - aggregates
  - molds
  - spatulas
  - bowls
  - hammer



NOTE: It generally takes 4 hours to bring aggregates & binder to mixing temperature. RAP will be heated in a separate pan for a maximum of 2 hours to minimize binder aging.

Mixing and Compaction Temps



Mixing Temp = 290

Comp Temp = 270

Prepare Samples

- Pour aggregate into mixing bowl
- Weigh in asphalt
- Mix until all aggregate is coated

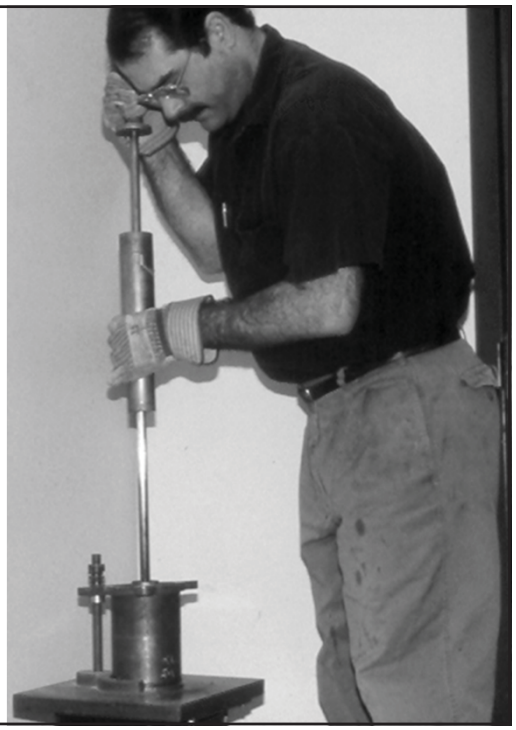
Proper "Curing" after mixing- 2 hours at mixing temperature in covered container

Prepare Samples

- Transfer sample into heated mold

Prepare Samples

- Marshall Hammer
  - **10 lbs**
  - **18” Drop**
  - **Slant foot , rotating base**
  - **Compact 50 blows/side**
- SGC
  - **600 Kpas pressure**
  - **30 rev./min. rotating base**
  - **1.16 deg. internal angle**
  - **75 gyrations (typ)**

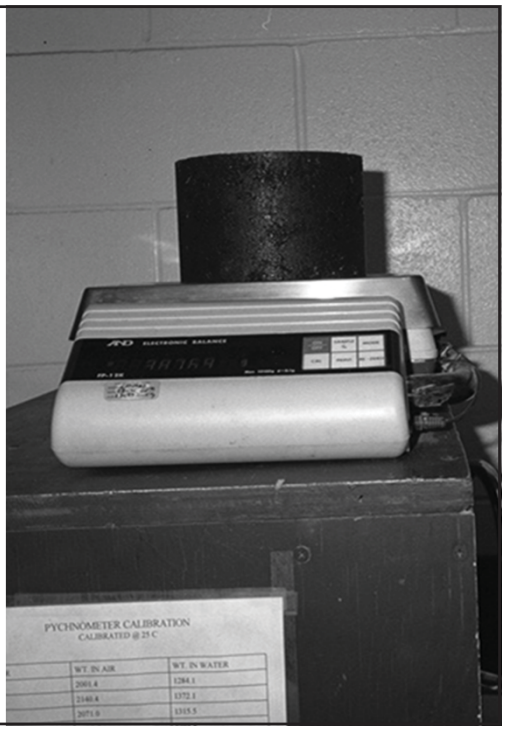


Prepare Samples

- Cool in Molds
- Extract from Molds
- Cool Compacted Specimens to room temperature (overnight)

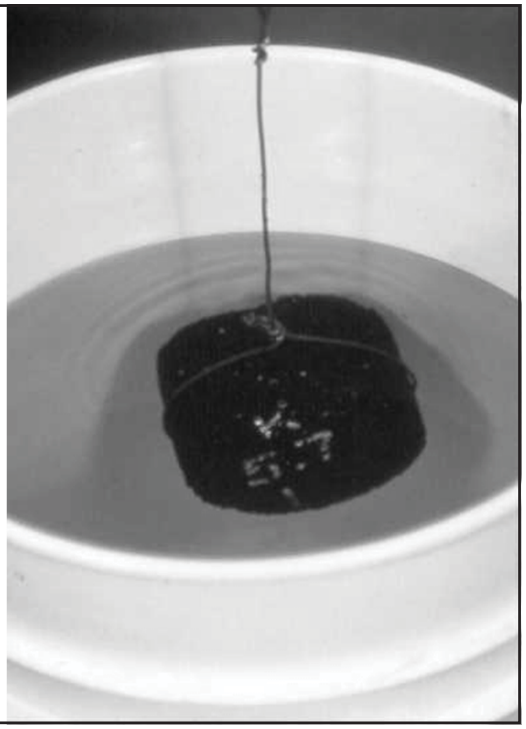
Bulk Specific Gravity

- Weight of Compacted Specimen in Air
- AASHTO T245/T166 Marshall
- AASHTO T312/T166 Gyratory



Bulk Specific Gravity

- Weight of Compacted Specimen in Water



Bulk Specific Gravity

- Weight of Compacted Specimen Saturated Surface Dry (SSD)

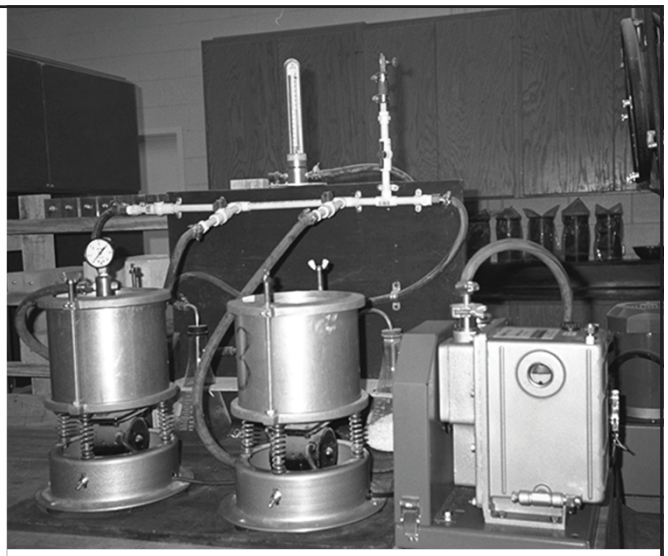
Bulk Specific Gravity, G_{mb}

- G_{mb} = F/(G-H)
  - F - Dry weight
  - G - SSD weight
  - H - weight in water

Average the results for two samples at each asphalt content (three for Marshall)

Maximum Specific Gravity

- Specific gravity of specimen with zero air voids
- AASHTO T209



Theoretical Maximum Specific Gravity (Rice) Performed on Loose Samples

Evaluate Gyratory Data

- N*initial*
- N*design*
- N*max*

Evaluate Volumetrics and Performance Measures (if Specified)

Questions?

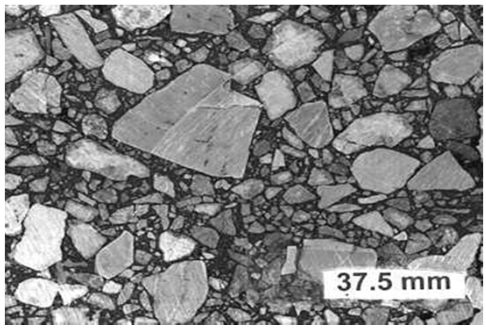
ND QC/QA HBP
Mix Controller
Aggregate Properties and Criteria

The First Step in Mix Design

- AGGREGATE EVALUATION
  - Aggregate Physical Properties
    - Toughness & Abrasion
    - Durability and Soundness
    - Cleanliness and Deleterious Materials
    - Particle Shape and Surface Texture
  - Aggregate Descriptive Properties
    - Gradation and Size
    - Specific Gravity and Absorption

Aggregates in Asphalt Construction

- Mineral aggregate has a great influence on the performance of an asphalt pavement as aggregates comprise 90 to 96 percent of the mixture weight and/or 82 to 88 percent of the aggregate volume.



Aggregates in Asphalt Construction

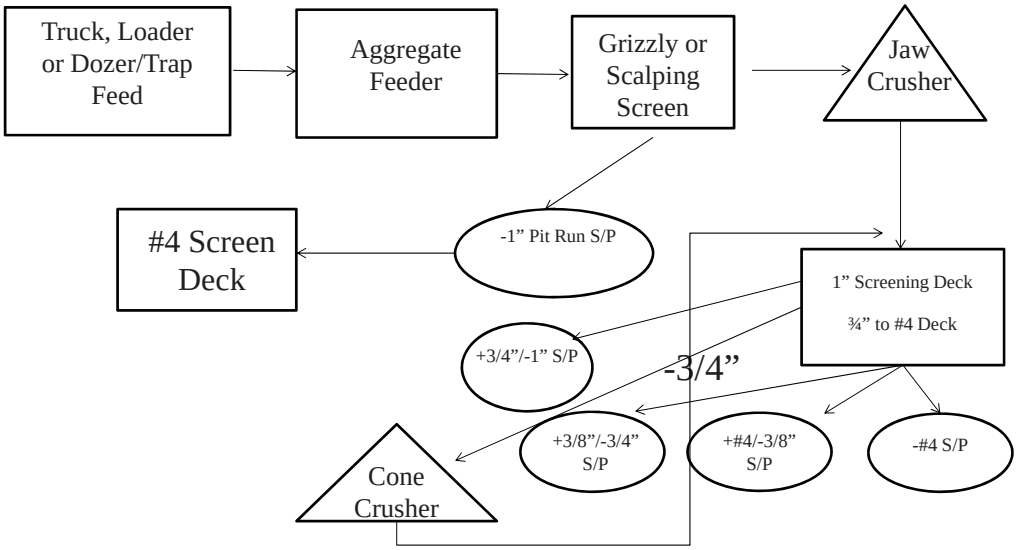
- **Processing aggregates** crushing, sizing, and/or washing to improve product characteristics
  - Natural Pit Materials
  - Quarried Bedrock

Aggregates in Asphalt Construction

<u>Reasons for crushing and screening</u>

- To reduce size
- To improve particle distribution
- To change surface texture to rough
- To change particle shape to angular

Simplified Crusher Set-up



Aggregates in Asphalt Construction

Reasons for washing rock/sand

- To remove clay adhering to rock surface
- To remove crusher dust

Aggregate Properties

The suitability of an aggregate for use in asphalt construction depends on the following:

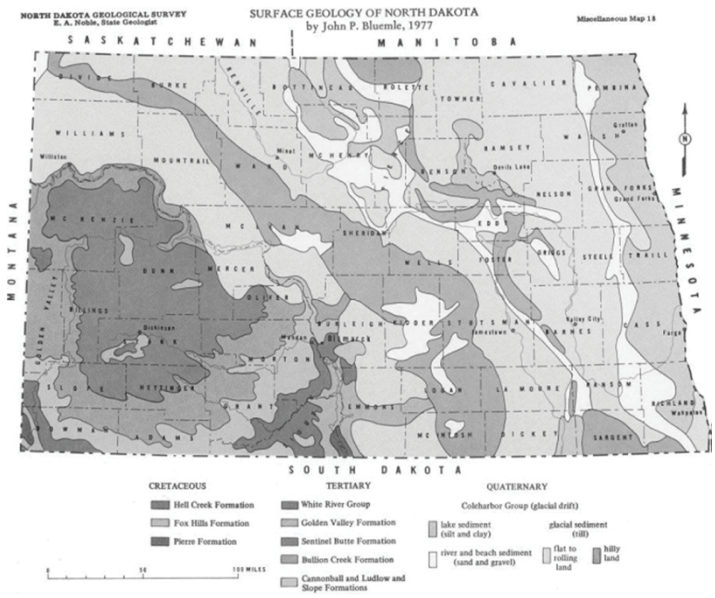
- Maximum particle Size
- Specific Gravity
- Toughness
- Absorption (Affinity for asphalt binder)
- Moisture Susceptibility
- Gradation (Particle size distribution)
- Cleanliness or clay content
- Particle shape and surface texture

Selection Based on Economics

Thought Process in Selection of Aggregate

- Proximity to Plant and/or Job-Site and Unit Cost
- Pre-Bid Testing for Viability
- Previous Use of Aggregate- Prior to Superpave
- Previous Use of Aggregate on Superpave Project
- Competitors Use of Given Aggregate Sources on Superpave Project

Geology of ND



Superpave
Aggregate Properties

- Consensus Properties - *Required*
  - Coarse Aggregate Angularity (CAA)
  - Fine Aggregate Angularity (FAA)
  - Flat, Elongated particles
  - Clay Content
- Source Properties - *Agency Option*
  - Toughness
  - Soundness
  - Deleterious Materials

Gyratory (*Superpave*)
Mixture & Aggregate Relationship

- Aggregate Tests
  - Consensus Properties - required
  - Source Properties – Agency option
- Aggregate Criteria
  - Based on Aggregate Blend
  - Based on Traffic and *Depth into Pavement*
- Design Aggregate Structure
  - 0.45 Power Chart
  - Controls Points and PCS points

Consensus Mineral Aggregate Tests

- Course Aggregate Angularity (Percentage of Fractured Particles in Coarse Aggregate; NDDOT 4)
- Fine Aggregate Angularity (AASHTO T 304 - Method A)
- Flat and Elongated Particles (ASTM D 4791)
- Sand Equivalent (AASHTO T 176)

Source Mineral Aggregate Tests (QC/QA Superpave)

- Shale Content (Lightweight Pieces in Aggregate: AASHTO T113 ND Modified)
- Los Angeles Abrasion (AASHTO T 96)
- Deleterious Material % Spall (NDDOT 3/AASHTO T112, Clay Lumps and Friable Particles in Aggregate)

Aggregate Size Definitions

100	***100***
100	***99***
90	**89**
72	**72**
65	**65**
48	**48**
36	**36**
22	**22**
15	**15**
9	**9**
4	**4**

- *Nominal Maximum* Aggregate Size
  - One size larger than the first sieve to retain more than 10%
- *Maximum* Aggregate Size
  - One size larger than nominal maximum size
- Both definitions are based on the standard ASTM sieve nest

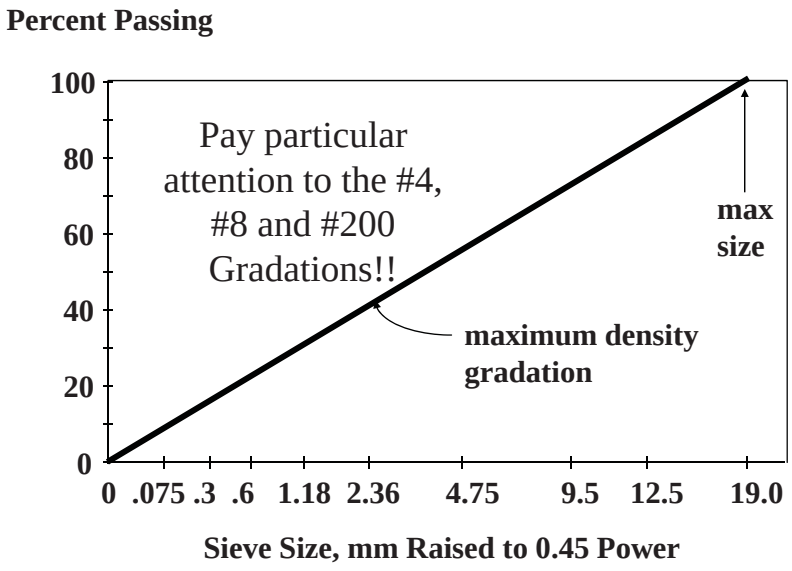
Rec. Min. Lift Thickness = 3 times NMAS

Aggregate Gradation

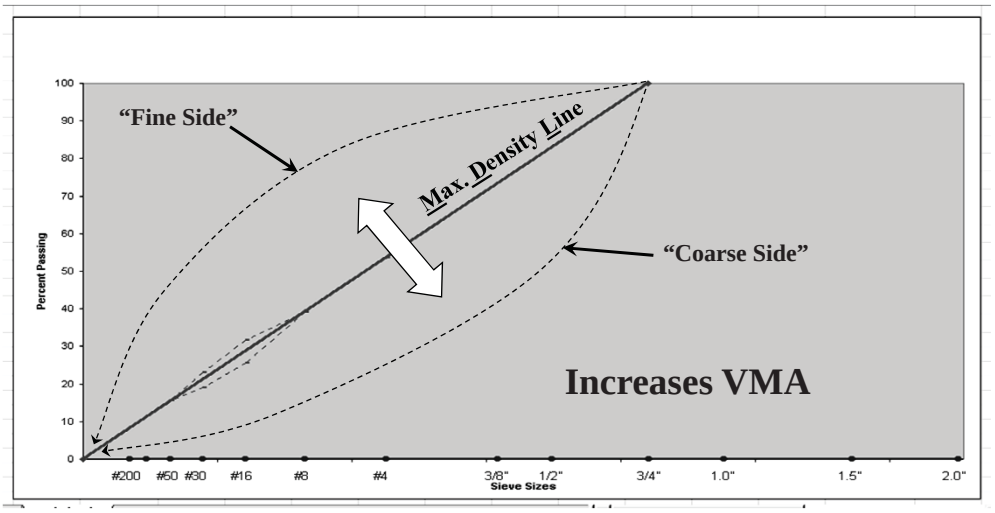
Is a primary factor in determining the volumetric properties of the HMA

Multiple Aggregate Sources and Sizing is Necessary to Obtain Balance

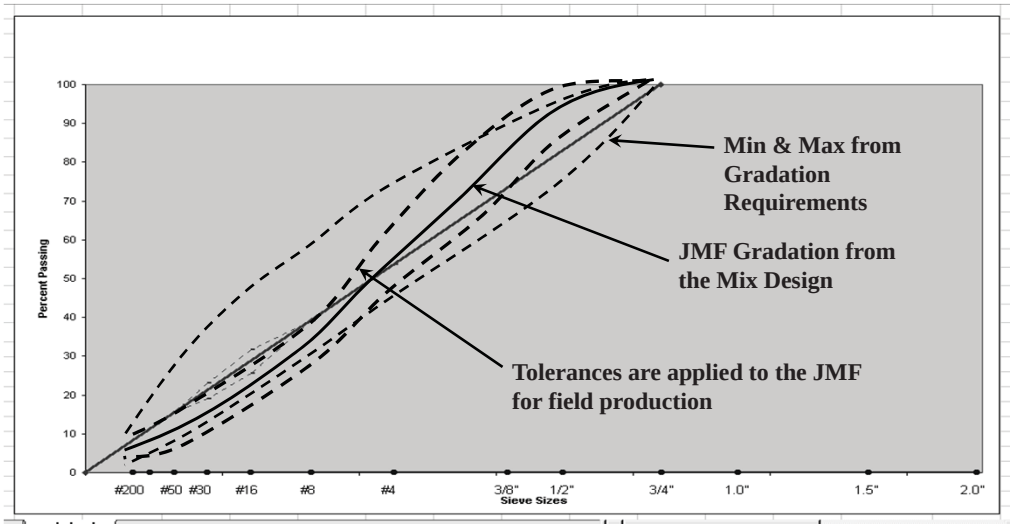
0.45 Power Grading Chart



45th Power Chart

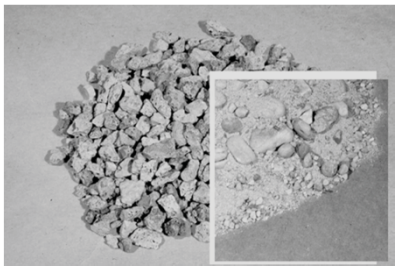


QC/QA Gradation Requirements



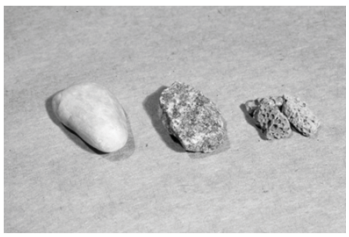
Aggregate Properties

- Particle shape
  - Also influences workability and compaction
  - Particle interlock, which produces higher mix strength, is higher with cubical shapes and lower for rounded particles
  - Percent crushing requirements (coarse/fine)



Aggregate Properties

- Surface texture
  - Rough surface increases mixture strength
  - Smooth surfaces produce “sliding effect”
  - Asphalt binders will typically adhere better to a rough textured surface
  - Surface texture will influence workability of the mixture



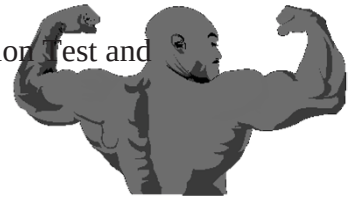
Aggregate Properties

- Cleanliness
  - Limits must be placed on the amount of foreign or deleterious substances in the aggregate
    - Vegetation
    - Shale
    - Soft particles
    - Clay lumps
    - Clay coatings on coarse aggregates

Aggregate Properties

Toughness

- An estimate of the ability of an aggregate to resist degradation during transportation, mixing, placement, and/or service loads
  - Surface -vs- lower layer toughness requirements
  - Influence of type of traffic to be using the pavement
  - Availability of local materials
  - Measured by the Los Angeles Abrasion Test and
  - Soundness Testing



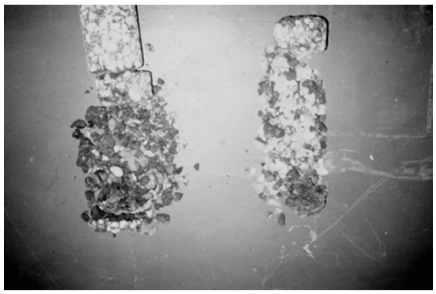
Los Angeles Abrasion Loss

AASHTO T 96 *

- Maximum Loss

Aggregate Properties

- Affinity for asphalt
  - Hydrophobic -vs- hydrophilic
  - Stripping
    - Separation of the asphalt from the surface of the aggregate through the action of water
    - Liquid anti-strip additive
    - Hydrated lime

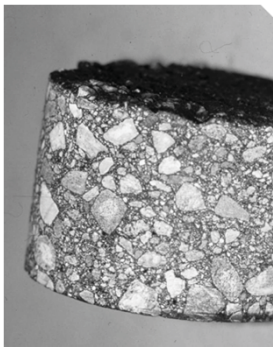


Superpave Aggregate Properties

- Consensus Properties
  - coarse aggr angularity
  - fine aggr angularity
  - flat, elongated particles
  - clay content
- Source Properties
  - toughness
  - soundness
  - deleterious materials

Aggregate Properties

- Absorption
  - Porosity of aggregate causes absorption of both water and asphalt binder
  - Additional amounts of asphalt binder needed
  - Additional drying time for mixing
  - Slag and other synthetic materials tend to be more absorptive than natural aggregates



More on Specific Gravities Later !

Questions ?

Thank You !

Dakota Asphalt Pavement Association Inc.

"Build with Asphalt"

ND QC/QA Asphalt Concrete Mix Design & Production Control

Aggregates and Mixture Volumetrics

Important HMA Mix Properties

- Stability
- Durability
- Impermeability
- Workability
- Flexibility
- Fatigue Resistance
- Skid Resistance

We want them all!

How?

- Materials Selection
- Volumetric design

Materials Selection

Aggregate

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

Asphalt Binder

- Makes up 4 – 7% of the mixture
- Acts as the "glue" or "muscle" of the mix
  - Flexibility
  - Durability

Obtaining the right balance

Achieved through

- Volumetric Analysis of the Mixture
- Performance Testing APA/AMPT/Stability & Historical Analysis (Pavement Management)

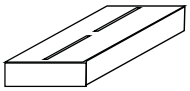
Volumetric Analysis Definition:

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

Intent of laboratory compaction?

Simulate the in-place density of HMA after it has endured several years of traffic in the roadway

In-place Density



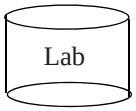
Air Voids

15-25% Before Rolling

6 – 9% After Rolling

Future Traffic

Design Density



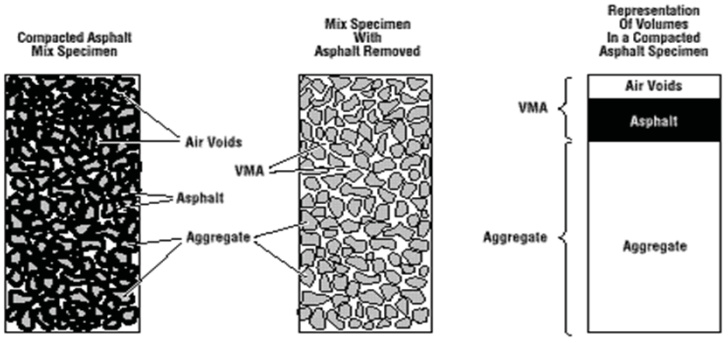
Air Voids

3 – 5% Marshall

4% Superpave

Importance of Volumetric Properties

Experience shows that % air voids and the voids in the mineral aggregate relate to performance



Note: For simplification, the volume of absorbed asphalt is not shown.

Volumetric Analysis History:

- Not a new concept; has played a role in most mixture design methods
- Is currently the best available method to readily measure mixture properties in the field on plant produced mix.
- We must first understand Specific Gravity Concepts and Aggregate Characteristics

Nomenclature for Specific Gravity

- G_{xy} - Where G Equals Specific Gravity
  - 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

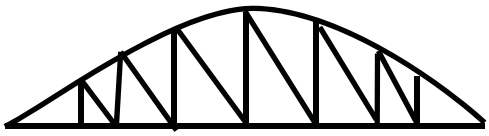
Determine Aggregate Specific Gravities

What is a Specific Gravity ?

It is the ratio between the density of <u>anything</u> compared to the density of water

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

Specific Gravity is the bridge between volume and mass



Volume $G = \frac{M}{V}$ **Mass**

V=M/ G **M=V*G**

In the metric system
specific gravity = unit weight

Specific Gravity

Relates Volume

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

mass of object

volume of object

specific gravity of object

density of water

Specific Gravity

Relates Mass

volume of object

$$M = V \times G \times 1.000$$

mass of object

specific gravity of object

density of water

Specific Gravity

- Specific Gravity and Absorption of Aggregates are determined in the Laboratory
  - AASHTO T-84 *Specific Gravity and Absorption of Fine Aggregate*
  - AASHTO T-85 *Specific Gravity and Absorption of Coarse Aggregate*

Specific Gravities

The specific gravity of 3 different materials are obtained and used in volumetric analysis

- Asphalt – Furnished by the supplier
- Mixture - cannot be determined until mixture testing is completed
- Aggregate -

AASHTO T84 Specific Gravity and Absorption in Fine Aggregate

AASHTO T85 Specific Gravity and Absorption in Coarse Aggregate

Aggregate Specific Gravity

- Mineral aggregate is porous.
- Will absorb water and asphalt to a variable degree.
- Three different specific gravities are needed to account for these variations.

Gsb = Bulk Specific Gravity

Gsa = Apparent Specific Gravity

Gse = Effective Specific Gravity

3 Different Aggregate Specific Gravities

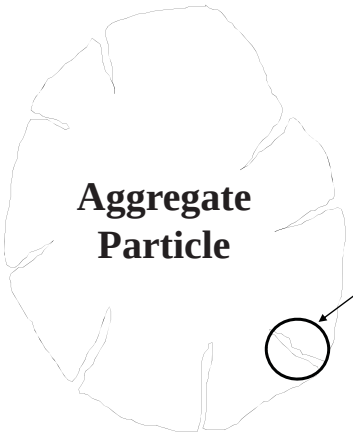
- Bulk (G_{sb}) Volume
- Apparent (G_{sa}) Volume
  - excludes absorbed water volume
- Effective (G_{se}) Volume
  - excludes absorbed asphalt volume
  - Must use mixture testing to determine Gsa Volume. (Gmm)

Same Mass

Different Volumes

Aggregate Bulk Specific Gravity

"SSD" Level



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

Bulk Volume = solid volume + water permeable pore volume

Uses SSD condition – the aggregate is Saturated but the Surface is Dry

This is a measured specific gravity

Coarse Aggregate Gsb

- Laboratory testing gives us 3 values
  - A = oven dry wt. in air
  - B = SSD wt. in air
  - C = SSD wt in water

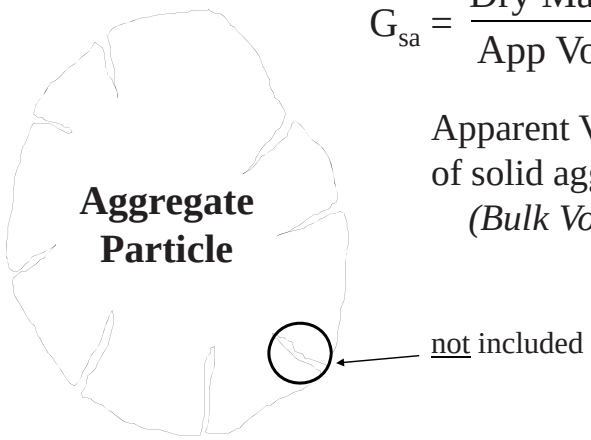
Bulk Volume

$$Gsb = A / (B - C)$$

Aggregate Apparent Specific Gravity

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

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



This is a measured specific gravity

Coarse Aggregate Gsa

- Laboratory testing gives us 3 values
  - A = oven dry wt. in air
  - B = SSD wt. in air
  - C = SSD wt in water

Apparent Volume

$$Gsa = A / (A - C)$$

Absorption is very critical !

- Water absorption is easily determined during Gs testing
- Problem: Asphalt doesn't absorb into the aggregate as far as water does
- Gmm testing accurately allows us to calculate the volume of a mixture <u>after</u> absorption has occurred.
- Asphalt absorption is considered to be constant in the mix design working range

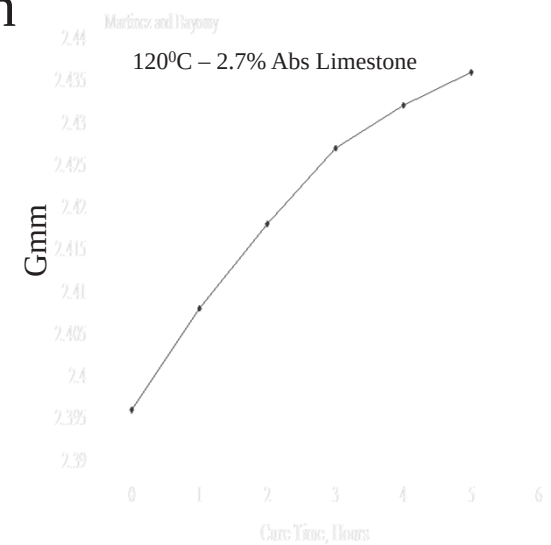
Proper "Curing" of Mix

Proper curing of mix

- To simulate effects on mix during production
- Standard curing time is two hours for low absorption aggregate
- When high absorption aggregate is used, *(>2% water absorption)*, curing time should be increased to four hours
- Curing times on field QC testing may be reduced depending on sample location

Absorption

- Absorption continues to occur over a period of time.
- Results in significant variation in G_{mm} over time



Bulk specific gravity of coarse aggregate

- **In the AASHTO T 85 and ASTM C127 procedures, the visual method of determining when aggregates reach a SSD condition is highly operator dependent.**
- **Both standard test procedures, including aggregate soaking time, cannot be completed in one work day.**
- **All of the precision estimates for AASHTO T 85 and ASTM C127 from 1998 through 2005 by the AMRL are much greater than those cited in the standards, and they vary significantly from year to year which is presumed to be due to the use of different aggregate sources in the proficiency sample program.**
- **The AggPlus system using the CoreLok device is commercially available as an alternative method for determining G_{sb} of coarse aggregate. Another device, the Gilson Rapid Water Displacement, is being developed.**
- **Recent studies have evaluated the AggPlus system using the vacuum-seal device against the AASHTO T 85 procedure. The AggPlus system does not require the determination of SSD condition and soaking time. The AggPlus produced higher specific gravity values that were significantly different (both statistically and practically) from those produced by AASHTO T 85. The difference was greater for highly absorptive coarse aggregate. Both methods had similar reproducibility**

■Bulk specific gravity of fine aggregate

- **In AASHTO T 84 and ASTM C128, the SSD condition of various fine aggregates is not consistently determined using the cone and tamp technique.**
- Both standard test methods, including aggregate soaking time, cannot be completed in one work day.
- As with the standard test methods for bulk specific gravity of coarse aggregate, most of the **precision estimates for AASHTO T 84 and ASTM C128 published annually on the AMRL website are greater than those cited in the standards, and they vary significantly from year to year.**
- **Several modifications have been made by states to improve the process of determining the SSD condition. However, all modifications still require technician judgment, and the reproducibility improvement is not found in the literature.**
- Alternate methods for determining G_{sb} of fine aggregate include the CoreLok, SSDetect, and Phunque. In addition, the Langley de-airing device can be used with AASHTO T 84.
- Most recent studies published have focused on the CoreLok and SSDetect devices. Both devices do not require the determination of SSD weight and soaking time. However, the G_{sb} values determined using either procedure were significantly different from those produced using AASHTO T 84. **Differences were greater for more angular fine aggregate with aggregate having higher dust contents**. The SSDetect had the best precision indices, then AASHTO T 84 and the CoreLok.

NCHRP 4-35/NCAT

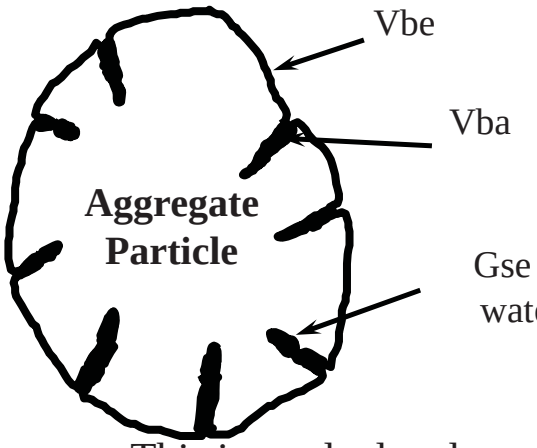
The missing link

- Gsb gives us the Bulk Vol. of the agg.
- Gsa gives us the Apparent Vol. Of the agg.
- Gmb gives us the Bulk Vol. of the mix
- Gmm gives us the “Minimum” Vol. of the mix

Gse is the missing link

Gse = Effective Specific Gravity

$$G_{se} = \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}}$$



Effective Volume (Vse)

(Vse = Vsb – Vba)

Gse includes the volume of water permeable voids not filled with asphalt

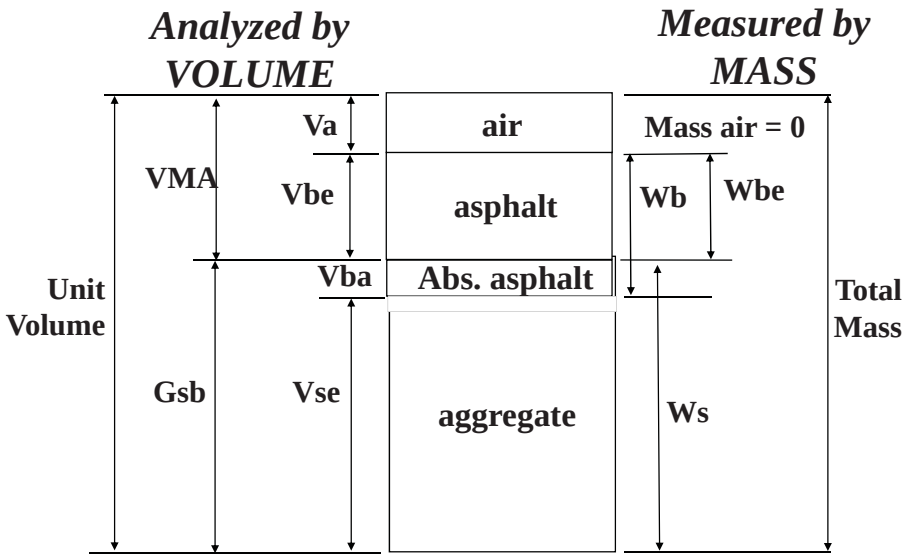
This is a <u>calculated</u> specific gravity

Mixture Volumetrics

A thorough understanding of aggregate specific gravity properties are needed to calculate the Mixture Volumetrics.

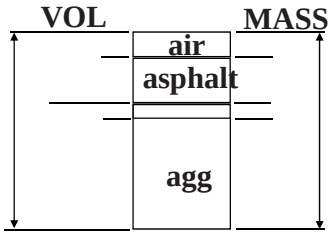
HMA Volumetric Terms

- Bulk specific gravity of mix, Gmb
- Maximum specific gravity of mix, G_{mm}
- Air voids of mix, V_a
- Voids in mineral aggregate, VMA
- Voids filled with asphalt, VFA
- Bulk specific gravity of aggregate, G_{sb}
- Effective specific gravity of aggregate, G_{se}
- Dust to binder ratio



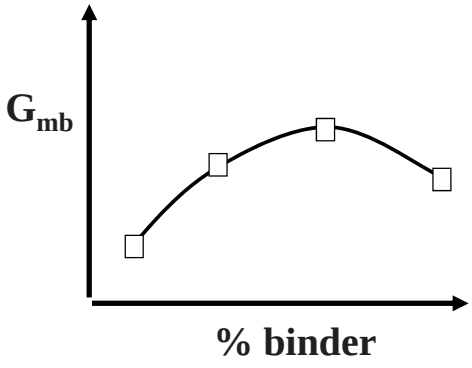
Specific Gravity bridges the Gap

Bulk Specific Gravity - Mix

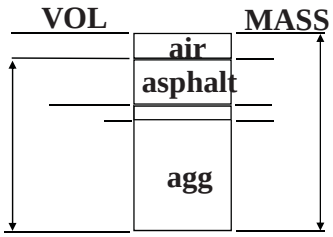


- Definition
  - mass of a unit volume of mix compared to unit volume of water
  - Use G_{mb}
- "Bulk Density"
  - Includes air voids in the mix

Bulk Specific Gravity (Unit Weight)

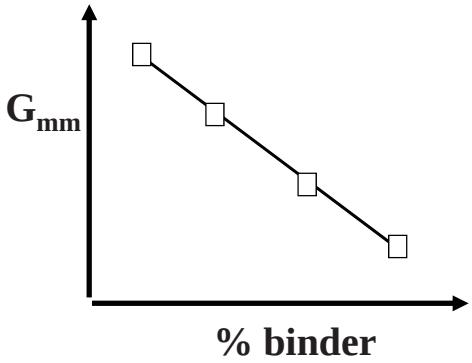


Maximum Theoretical Specific Gravity - Mix



- Definition
  - mass per volume of material containing no air voids, compared to unit volume of water
- Normally Use G_{mm}

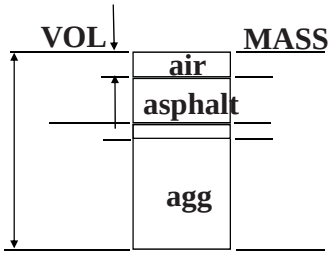
Maximum Theoretical Specific Gravity at Other Asphalt Contents



Importance of Air Voids

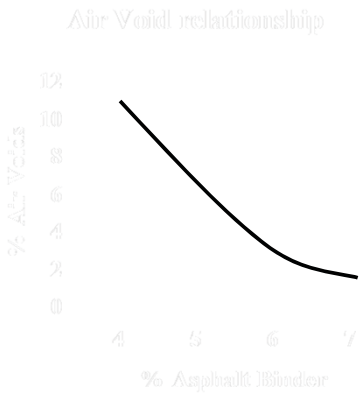
- Field performance has shown that mixtures designed below 3% air voids are susceptible to rutting and shoving
- Mixtures designed over 5% Air Voids are susceptible to raveling, oxidation and a general lack of durability
- 4% Air Void Design allows for thermal expansion of the binder along with a cushion for future compaction

Air Voids

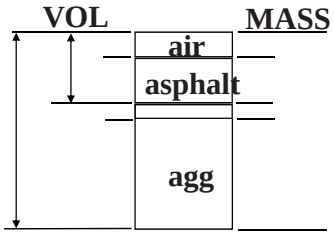


- Definition
  - volume concentration of air voids
- % by volume total mix, V_a

Air Voids



Voids in Mineral Aggregate (VMA)

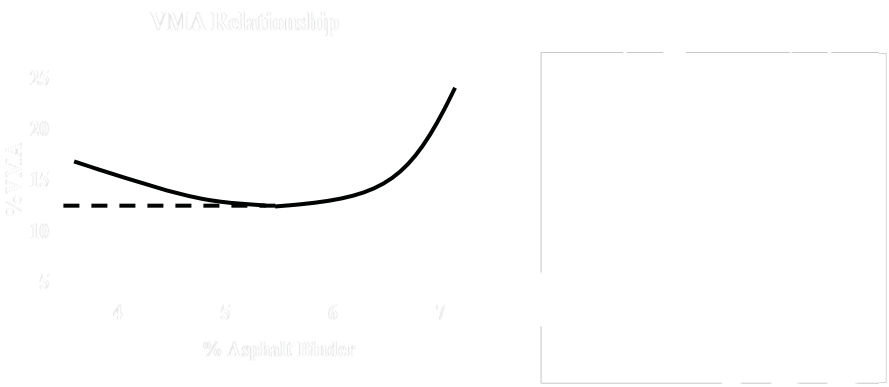


- Definition
  - volume concentration of *intergranular* void space in a compacted mix
- % by volume total mix
- *Does not* include volume of absorbed asphalt (use G_{sb} *not* G_{se})

Importance of VMA

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

VMA



Many Elements affect Volumetric Properties

Binder Quantity

Binder Properties

- Stiffness
- Modification
- Temperature

Every Mixture can be Different!!

Aggregate characteristics

- Gradation
- Particle shape
- Surface texture
- Hardness
- Absorption

- Air Voids (V_a), Voids in the Mineral Aggregate (VMA), Voids Filled with Asphalt (VFA), and Volume of Effective Binder (V_{be}) are calculated from the following well known equations:

2 $$VMA = \left(100 - \frac{G_{mb} P_s}{G_{sb}}\right)$$

$$VFA = \left(\frac{VMA - V_a}{VMA}\right) x100$$

1 $$V_a = \left(1 - \frac{G_{mb}}{G_{mm}}\right) x100$$

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

where:

- G_{mb} =bulk specific gravity of the compacted sample
- G_{mm} =maximum specific gravity of the asphalt mixture
- P_s =percentage (by mass) of aggregate in the total mixture
- G_{sb} =aggregate bulk specific gravity

- With these equations, the effects of the specific gravity results can be analyzed more closely and the following approximate relationships can be determined.
  - From Equation 1, if G_{mb} is held constant, the following relationship between *Air Voids* and G_{mm} is established: **when G_{mm} changes by +0.010, V_a changes by +0.4%.**
  - Likewise, if G_{mm} is held constant in Equation 1, the following relationship between *Air Voids* and G_{mb} is established: **when G_{mb} changes by +0.010, V_a changes by -0.4%.**
  - From Equation 2, when G_{sb} and P_s are held constant, the following relationship between VMA and G_{mb} is established: **when G_{mb} changes by +0.010, *VMA* changes by -0.4%.**
  - And also from equation 2, when G_{mb} and P_s are held constant, the following relationship between VMA and G_{sb} is established: when **G_{sb} changes by +0.010, *VMA* changes by +0.3%.**

Questions?

ND QC/QA Asphalt Concrete Mix Controller

Aggregate Analysis for Specification Compliance

Aggregate Analysis

- Determine the composite gradation for the Blend
- Determine all other properties that may be specified by the contract. (FAA, LA Wear, lightweight particles, etc.)
- We should not start the Mix Design Process until the aggregate materials meet the specifications

Calculating Aggregate Properties for the Composite blend

- All of the Aggregate Specifications are based on the composite blend
- They must be weighted by the bin split % <u>and</u> gradation

Marshall Aggregate Properties

- Fracture Faces
- Manufactured Fines
- Light Weight Particles (Coarse and Fine)
- Liquid Limit / Plasticity Index
- Toughness
- Soundness

Gyratory (*Superpave*) Mixture & Aggregate Relationship

- Aggregate Tests
  - Consensus Properties - required
  - Source Properties – Agency option
- Aggregate Criteria
  - Based on Aggregate Blend
  - Based on Traffic and *Depth into Pavement – ND FAA 40-45*
- Design Aggregate Structure
  - 0.45 Power Chart
  - Controls Points and PCS points

Superpave Aggregate Properties

- Consensus Properties - *Required*
  - Coarse Aggregate Angularity (CAA)
  - Fine Aggregate Angularity (FAA)
  - Flat, Elongated particles
  - Clay Content
- Source Properties - *Agency Option*
  - Toughness
  - Soundness
  - Deleterious Materials

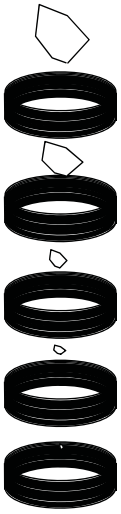
Consensus Mineral Aggregate Tests (QC/QA Gyratory)

- Course Aggregate Angularity (Crushed Particles)
- Fine Aggregate Angularity (AASHTO T 304 - Method A)
- Flat and Elongated Particles (ASTM D 4791)
- Sand Equivalent (AASHTO T 176 - use alternate method No. 2,Pre-wet to get sample and then dried before testing)

Source Mineral Aggregate Tests (QC/QA Gyratory)

- Lightweight Particles
- Los Angeles Abrasion * (AASHTO T 96)

Superpave Aggregate Gradation



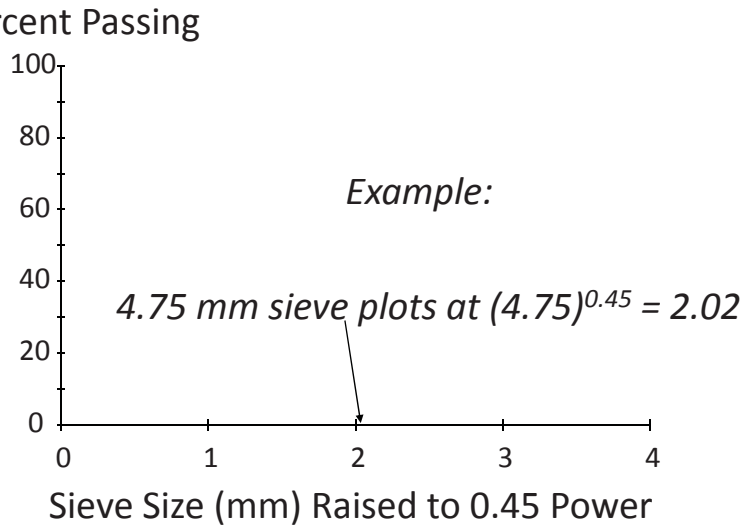
- Use 0.45 Power Gradation Chart
- Blend Size Definitions
  - maximum size
  - nominal maximum size
- Gradation Limits
  - control points
  - PCS point (% passing the #8 < > 39)

Aggregate Size Definitions

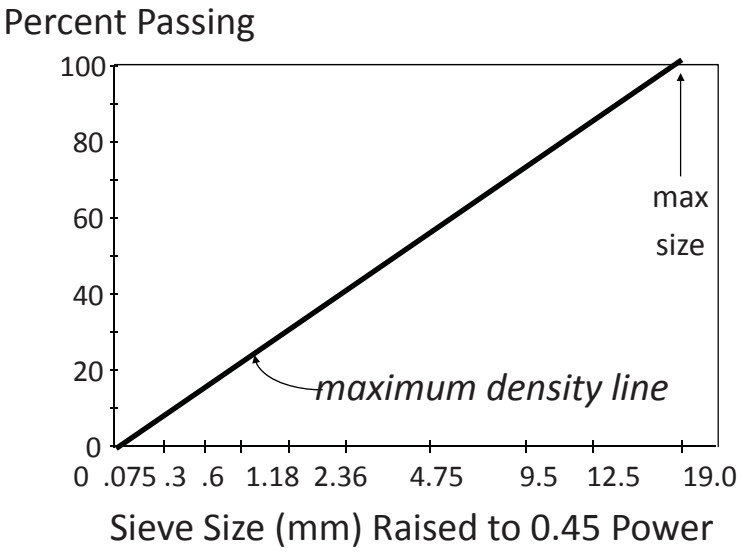
- *Nominal Maximum* Aggregate Size
  - one size larger than the first sieve to retain more than 10%
- *Maximum* Aggregate Size
  - one size larger than nominal maximum size

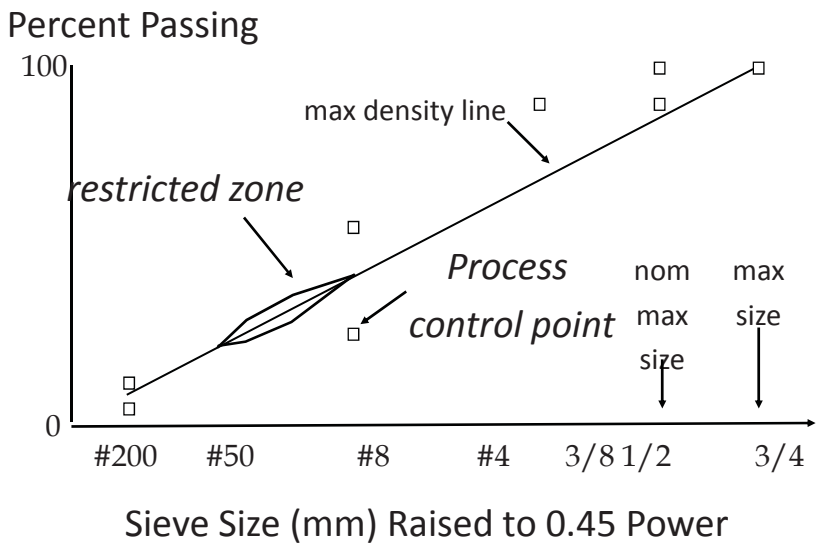
100
93
72
65
48
36
22
15
9
4

0.45 Power Grading Chart



0.45 Power Grading Chart





Determine Gradation for the Aggregate Blend

Calculate the blended aggregate gradation using the following formula

$$P = \frac{(A \times a) + (B \times b) + (C \times c) + \ldots}{100}$$

where,

P = the % of combined aggregate for a given sieve

A,B,C, = % passing a sieve for an individual stockpile

a,b,c, = individual % of stockpiles by weight

Example

Assuming the following data for the #4 sieve, calculate the total % Passing

Bin Split =>	25%	35%	30%	10%	Combined
	Agg.1	Agg.2	Agg.3	Agg.4	Blend
	2.8	21.4	98.8	99.3	

Example

Assuming the following data for the #4 sieve, calculate the total % Passing

Bin Split =>	25%	35%	30%	10%	Combined
	Agg.1	Agg.2	Agg.3	Agg.4	Blend
	2.8	21.4	98.8	99.3	47.8

$$\frac{(25 \times 2.8)+(35 \times 21.4)+(30 \times 98.8)+(10 \times 99.3)}{100}$$

Example

Sieve Size	25%	35%	30%	10%	Composite
mm	Agg.1	Agg.2	Agg.3	Agg.4	Blend
25	100.0	100.0	100.0	100.0	100.0
19	92.0	100.0	100.0	100.0	98
12.5	50.9	100.0	100.0	100.0	88
9.5	28.7	91.8	100.0	100.0	79
4.75	2.8	21.4	98.8	99.3	48
2.36	2.6	3.0	66.9	88.8	31
1.18	2.4	2.8	40.8	79.0	22
0.6	2.2	2.6	27.0	65.3	16
0.3	2.0	2.4	19.6	13.9	9
0.15	1.8	1.6	15.7	2.2	6
0.075	1.8	1.6	13.4	1.5	5.2

How much of the total + # 4 material is from Agg.1 ?

Liquid Limit, Plastic Limit and Plasticity Index

- The Liquid Limit is the water content at which a soil passes from a plastic to a liquid state.
- The Plastic Limit is the lowest water content at which a soil remains plastic.
- The Plasticity Index is the numerical difference between the Liquid Limit and the Plastic Limit.

The word “soil” in these tests shall mean the minus #40 (0.425 mm) sieve material.

Calculate the Remaining Aggregate Properties for the Composite Blend

- The blended consensus properties must be adjusted proportionately
- The contribution of one stockpile to the composite blend is not equal to the percentage of the bin split
- It is dependent on the gradation of the material.

Calculate +#4 % Fractured Face for the Blend

$$\%FF_{blend} = \frac{\sum_{1}^{n} A \times \left(1 - \frac{B}{100}\right) \times \left(\frac{C}{100}\right)}{1 - \frac{D}{100}}$$

$\%FF_{blend}$ = Percent Fractured Faces for the Total Blend
A = stockpile % in the Total Blend
B = % passing the #4 sieve of individual stockpile
C = % FF of individual stockpile
D = % passing the #4 sieve of total blend

Example

Sieve Size	25%	35%	30%	10%	Composite
	Agg.1	Agg.2	Agg.3	Agg.4	Blend
# 4	2.8	21.4	98.8	85.0	46.3
% -FF	100	100.0	100.0	0	

$\%FF_{blend} =$

Example

Sieve Size	25%	35%	30%	10%	Composite
	Agg.1	Agg.2	Agg.3	Agg.4	Blend
# 4	2.8	21.4	98.8	85.0	46.3
% 2-FF	100	100.0	100.0	0	

$$\%FF_{blend} = \frac{\left(25 \times (1-.028) \times (1.00)\right) + \left(35 \times (1-.214) \times (1.00)\right) + \left(30 \times (1-.988) \times (1.00)\right) + \left(10 \times (1-.850) \times (0)\right)}{(1-.463)}$$

$$= \frac{24.3 + 27.5 + 0.4 + 0}{.537} = 97.2$$

% Manufactured Fines

$$\%\ Man.\ Fines_{blend} = \sum_{1}^{n} \frac{A\left(\frac{B}{100}\right)}{C} \times D$$

A = stockpile % in the Total Blend
B = % passing the #4 sieve of individual stockpile
C = % passing the # 4 sieve of total blend
D = % Manufactured Fines of each stockpile

Example

Sieve Size	25%	25%	20%	30%	Composite
	Agg.1	Agg.2	Agg.3	Agg.4	Blend
% Passing #4	2.8	21.4	98.8	85.1	51.3
% Man. Fines	100	100.0	100.0	0	

% Man. Fines =

Example

Sieve Size	25%	25%	20%	30%	Composite
	Agg.1	Agg.2	Agg.3	Agg.4	Blend
% Passing #4	2.8	21.4	98.8	85.1	51.3
% Man. Fines	100	100.0	100.0	0	

$$\text{\% Man. Fines} = \left(\frac{25 \times \left(\frac{2.8}{100}\right)}{51.3} \times 100\right) + \left(\frac{25 \times \left(\frac{21.4}{100}\right)}{51.3} \times 100\right)$$

$$+ \left(\frac{20 \times \left(\frac{98.8}{100}\right)}{51.3} \times 100\right) + 0 = 1.4 + 10.4 + 38.5 + 0$$

$$= \mathbf{50.3\ \%}$$

+ #4 Lt. Wt. Particles for the Blend

$$+\#4\ Lt\ Wt_{blend} = \frac{\sum_{1}^{n} A \times \left(1 - \frac{B}{100}\right) \times \left(\frac{C}{100}\right)}{1 - \frac{D}{100}}$$

$+\#4\ Lt\ Wt_{blend}$ = Percent + #4 Lt. Wt. Particles for the Total Blend

A = stockpile % in the Total Blend
B = % passing the #4 sieve of individual stockpile
C = % + #4 Lt. Wt. Particles of individual stockpile
D = % passing the #4 sieve of total blend

- #4 Lt. Wt. Particles for the Blend

$$\text{- \#4 Lt. Wt.}_{blend} = \sum_{1}^{n} \frac{A \times \left(\frac{B}{100}\right)}{C} \times D$$

A = stockpile % in the Total Blend
B = % passing the #4 sieve of individual stockpile
C = % passing the # 4 sieve of total blend
D = % Lt. Wt. Particles of each stockpile

Estimated
Liquid Limit and PI for the Blend

$$\text{LL or PI}_{blend} = \sum_{1}^{n} \frac{A \times \left(\frac{B}{100}\right)}{C} \times D$$

A = stockpile % in the Total Blend
B = % passing the #40 sieve of individual stockpile
C = % passing the # 40 sieve of total blend
D = LL or PI of each stockpile

This value should be verified on a composite sample

LL Example

% Bin Split =>	25%	25%	20%	30%	Composite
Sieve Size	Agg.1	Agg.2	Agg.3	Agg.4	Blend
# 40	2.8	5.1	45	32	20.6
LL	18	17	17	28	
PI	NP	NP	NP	6.2	

LL =

LL Example

% Bin Split =>	25%	25%	20%	30%	Composite
Sieve Size	Agg.1	Agg.2	Agg.3	Agg.4	Blend
# 40	2.8	5.1	45	32	20.6
LL	18	17	17	28	
PI	NP	NP	NP	6.2	

$$LL = \left(\frac{25 \times (.028)}{20.6} \times 18\right) + \left(\frac{25 \times (.051)}{20.6} \times 17\right)$$

$$+ \left(\frac{20 \times (.45)}{20.6} \times 17\right) + \left(\frac{30 \times (.32)}{20.6} \times 28\right)$$

$$= .61 + 1.05 + 7.43 + 13.05 = \mathbf{22.14}$$

PI Example

% Bin Split =>	25%	25%	20%	30%	Composite
Sieve Size	Agg.1	Agg.2	Agg.3	Agg.4	Blend
# 40	2.8	5.1	45	32	20.6
LL	18	17	17	28	
PI	NP	NP	NP	6.2	

PI =

PI Example

% Bin Split =>	25%	25%	20%	30%	Composite
Sieve Size	Agg.1	Agg.2	Agg.3	Agg.4	Blend
# 40	2.8	5.1	45	32	20.6
LL	18	17	17	28	
PI	NP	NP	NP	6.2	

$$PI = \left(\frac{25 \times (.028)}{20.6} \times 0\right) + \left(\frac{25 \times (.051)}{20.6} \times 0\right)$$

$$+ \left(\frac{20 \times (.45)}{20.6} \times 0\right) + \left(\frac{30 \times (.32)}{20.6} \times 6.2\right)$$

$$= 0 + 0 + 0 + 2.89 = \mathbf{2.9}$$

L.A. Abrasion Loss

The Blended value for the Wear Test is dependent upon the Class of Test Performed

Material Size		Material Grading Size			
Passing	Retained	A	B	C	D
1 1/2"	1"	1250g			
1"	3/4"	1250g			
3/4"	1/2"	1250g	2500g		
1/2"	3/8"	1250g	2500g		
3/8"	1/4"			2500g	
1/4"	# 4			2500g	
# 4	# 8				5000g
Total Sample Weight		5000g	5000g	5000g	5000g
# of Metal Spheres		12	11	8	6
500 Revolutions					

Sieve tested sample over a # 12 Seive

(Material passing the # 12 / Original Sample wt.)x 100 = Wear Loss

L. A. Abrasion Test

$$\%\ Wear\ Loss_{blend} = \frac{\sum_{1}^{n} A \times \left(1 - \frac{B}{100}\right) \times \left(\frac{C}{100}\right)}{1 - \frac{D}{100}}$$

% Wear Loss

$_{blend}$ = Percent LA Wear Loss for the Total Blend
A = stockpile % in the Total Blend
B = % passing the #4 sieve of individual stockpile
C = % Loss of individual stockpile
D = % passing the #4 sieve of total blend

Same as Fractured Face Calculation

Combined Gsb & Gsa for each stockpile

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

Combined Gsb & Gsa for each stockpile

$$Gsx = \frac{P_1 + P_2}{\frac{P_1}{G_1} + \frac{P_2}{G_2}}$$

Gs*x* = the bulk or apparent specific gravity of an individual aggregate stockpile
P1 = % retained on the 4.75mm sieve
G1 = specific gravity of the material retained on the 4.75mm sieve
P2 = % passing the 4.75mm sieve
G2 = specific gravity of the material passing the 4.75mm sieve

Example

Bin Split %=>	25%	**35%**	30%	10%	Composite
Sieve Size	Agg.1	**Agg.2**	Agg.3	Agg.4	Blend
4.75 mm	2.8	**21.4**	98.8	85.0	

Calc Gsb for Agg.2 if +#4 Gsb = 2.576 & - #4 Gsb = 2.601

$Gsb =$

Example

Bin Split %=>	25%	**35%**	30%	10%	Composite
Sieve Size	Agg.1	**Agg.2**	Agg.3	Agg.4	Blend
4.75 mm	2.8	**21.4**	98.8	85.0	46.3

Calc Gsb for Agg.2 if +#4 Gsb = 2.576 & - #4 Gsb = 2.601

$$Gsb = \frac{78.6 + 21.4}{\frac{78.6}{2.576} + \frac{21.4}{2.601}} = \frac{100.0}{30.51 + 8.23} = \mathbf{2.581}$$

Judgment is needed when evaluating each stockpile

- Aggregate material with a small amount of coarse or fine material may not need to be tested
- The coarse or fine Gs may be assumed from the tested portion or the use of results from another similar material may be appropriate.

Example

Sieve Size		25%	35%	30%	10%
mm	US	Agg.1	Agg.2	Agg.3	Agg.4
25	1"	100.0	100.0	100.0	100.0
19	3/4"	92.0	100.0	100.0	100.0
12.5	1/2"	50.9	100.0	100.0	100.0
9.5	3/8"	28.7	91.8	100.0	100.0
4.75	#4	2.8	21.4	98.8	99.3
2.36	#8	2.6	3.0	66.9	88.8
1.18	#16	2.4	2.8	40.8	79.0
0.6	#30	2.2	2.6	27.0	65.3
0.3	#50	2.0	2.4	19.6	13.9
0.15	#100	1.8	1.6	15.7	2.2
0.075	#200	1.8	1.6	13.4	1.5
	G_{sb}	2.719	2.670	2.587	2.618
	G_{sa}	2.766	2.745	2.741	2.711

Combine Gsb & Gsa of all stockpiles into 1 value for the blend

$$Gsx = \frac{P_1 + P_2 + \ldots\ldots P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \ldots + \frac{P_n}{G_n}}$$

Example

	25%	35%	30%	10%
	Agg.1	Agg.2	Agg.3	Agg.4
Gsb	2.719	2.670	2.587	2.618

$$Gsb =$$

Example

	25%	35%	30%	10%
	Agg.1	Agg.2	Agg.3	Agg.4
Gsb	2.719	2.670	2.587	2.618

$$Gsb = \frac{25 + 35 + 30 + 10}{\frac{25}{2.719} + \frac{35}{2.670} + \frac{30}{2.587} + \frac{10}{2.618}}$$

$$= \frac{100}{37.719} = \mathbf{2.651}$$

Combined Gs for the Blend

- Has to be done for both Gsb and Gsa
- The same equation may be used for both

Moisture absorption of the blended mineral aggregates

- This not a mandatory requirement
- For informational use only
- % water absorption of each stockpile is easily calculated while running Gs tests
- Can be very helpful to monitor as you build your knowledge base

Determine % Abs for each stockpile

$$Abs_{individual} = \frac{(P_1 \times A_1) + (P_2 \times A_2)}{100}$$

, Abs,individual = the water absorption of an individual aggregate stockpile
P1 = % retained on the 4.75mm sieve
A1 = the water absorption of the aggregate retained on the 4.75mm sieve
P2 = % passing the 4.75mm sieve
A2 = the water absorption of the aggregate passing the 4.75mm sieve

Example

Sieve Size		25%
mm	US	Agg.1
4.75	#4	2.8
	Coarse Abs	.65
	Fines Abs	.98

$Abs_{individual} =$

Example

Sieve Size		25%
mm	US	Agg.1
4.75	#4	2.8
	Coarse Abs	.65
	Fines Abs	.98

$$Abs_{individual} = \frac{(97.2 \times .65) + (2.8 \times .98)}{100}$$

$$= 0.66\%$$

Determine % Abs for the trial blend

$$Abs_{blend} = \frac{(P_1 \times A_1) + (P_2 \times A_2) + \ldots (Pn \times An)}{100}$$

$Abs,_{blend}$ = the water absorption of the total aggregate blend

P_1, P_2, … = individual % of stockpiles by weight

A_1, A_2, … = % water absorption of the aggregate stockpiles

Example

	25%	35%	30%	10%
	Agg.1	Agg.2	Agg.3	Agg.4
Absorption	0.68	1.05	0.98	1.87

$$Abs_{blend} =$$

Example

	25%	35%	30%	10%
	Agg.1	Agg.2	Agg.3	Agg.4
Absorption	0.68	1.05	0.98	1.87

$$Abs_{blend} = \frac{(25 \times 0.68) + (35 \times 1.05) + (30 \times 0.98) + (10 \times 1.87)}{100}$$

$$= \frac{101.85}{100} = 1.02\ \%$$

Determine FAA for blend

$$\% FAA_{blend} = \sum_{1}^{n} \frac{A\left(\frac{B}{100}\right)}{C} \times D$$

, FAA_{blend} = Fine Aggregate Angularity of the blend
n = Number of Stockpiles
A = Stockpile % in Total Blend
B = % Pass #4 Sieve Individual Stockpile *n*
C = % Pass #4 of Total Blend
D = FAA of individual Stockpile *n*

Example

Blend	25%	25%	20%	30%	Composite
	Agg.1	Agg.2	Agg.3	Agg.4	Blend
#4	2.8	21.4	98.8	85.1	51.3
FAA	39.0	37.5	43.2	38.7	

$$FAA_{blend} = \frac{[\{25 \times 0.028 \times 39.0\}+\{25 \times 0.214 \times 37.5\}+\{20 \times 0.988 \times 43.2\}+\{30 \times 0.851 \times 38.7\}]}{51.3}$$

$$= 40.3$$

Determine Sand Equivalent for Blend

$$SE_{blend} = \sum_{1}^{n} \frac{A\left(\frac{B}{100}\right)}{C} \times D$$

SE_{blend}	= Sand Equivalent of the blend
n	= Number of Stockpiles
A	= Stockpile % in Total Blend
B	= % Pass #4 Sieve Individual Stockpile *n*
C	= % Pass #4 of Total Blend
D	= SE of individual Stockpile *n*

Example

Blend	25%	25%	20%	30%	Composite
	Agg.1	Agg.2	Agg.3	Agg.4	Blend
#4	2.8	21.4	98.8	85.1	51.3
SE	60	59	54	46	

$$SE_{blend} = \frac{[\{25 \times 0.028 \times 60\}+\{25 \times 0.214 \times 59\}+\{20 \times 0.988 \times 54\}+\{30 \times 0.851 \times 46\}]}{51.3}$$

$$= 50.6 \sim 51$$

Determine Flat Elongated for Blend

$$\%FE_{blend} = \frac{\sum_{1}^{n} A \times \left(1 - \frac{B}{100}\right) \times \left(\frac{C}{100}\right)}{1 - \frac{D}{100}}$$

, FE_{blend} = Flat Elongated of the blend

- n = Number of Stockpiles
- A = Stockpile % of Blend
- B = % Passing the #4 Sieve of individual stockpile
- C = % Flat Elongated of individual stockpile
- D = % Passing the #4 Sieve entire blend

Example

Blend	25%	25%	20%	30%	Composite
	Agg.1	Agg.2	Agg.3	Agg.4	Blend
#4	2.8	21.4	98.8	85.1	51.3
FE	1.6	2.2	0	0	

$$\%FE_{blend} = \frac{[\{25 \times (1-.028) \times 0.016\}+\{25 \times (1-.214) \times 0.022\}+0+0]}{(1-.513)}$$

$$= \frac{0.39 + 0.43 + 0 + 0}{.487} = 1.7$$

Questions?

Asphalt Binder Specifications & Superpave

SHRP-Strategic Highway Research Program

- 1987-Present
- Original ISTEA Federal Bill
- $150 million/$50 million on AC Binders
- SUPERPAVE-Superior Performing Asphalt Pavements

SUPERPAVE

- Three Major Components
  - Asphalt Binder Specification
  - Mixture Design & Analysis System
  - Computer Software System

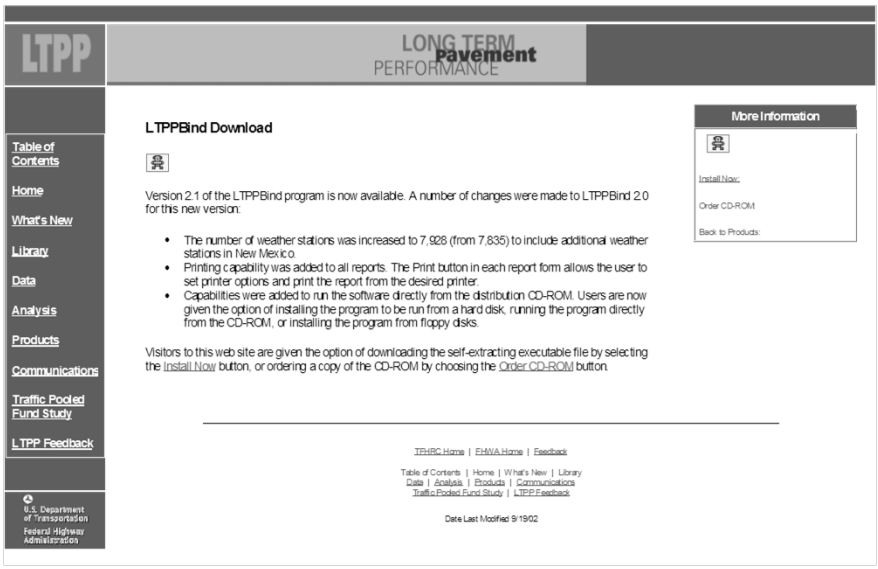
Mixture Design & Analysis

- Gyratory Hammer – Compacted Samples
- Volumetric Analysis
  - VMA
  - Voids
  - VFA
  - Aggregate Specifications (FAA, CAA)
- Performance Test Specification - Ongoing

Computer Software

- LTPP Sections – WEB Site: **http://www.tfhrc.gov/pavement/ltpp/bind / dwnload.htm**
- Mix Design – Temperature & Binder Selection
- WEB Site & Software Available
- Specifications Still Provisional

LTPP Bind Download



LTPP

LONG TERM PERFORMANCE Pavement

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U.S. Department of Transportation
Federal Highway Administration

LTPPBind Download

Version 2.1 of the LTPPBind program is now available. A number of changes were made to LTPPBind 2.0 for this new version:

- The number of weather stations was increased to 7,928 (from 7,835) to include additional weather stations in New Mexico.
- Printing capability was added to all reports. The Print button in each report form allows the user to set printer options and print the report from the desired printer.
- Capabilities were added to run the software directly from the distribution CD-ROM. Users are now given the option of installing the program to be run from a hard disk, running the program directly from the CD-ROM, or installing the program from floppy disks.

Visitors to this web site are given the option of downloading the self-extracting executable file by selecting the Install Now button, or ordering a copy of the CD-ROM by choosing the Order CD-ROM button.

More Information

Install Now:

Order CD-ROM

Back to Products:

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Date Last Modified 9/19/02

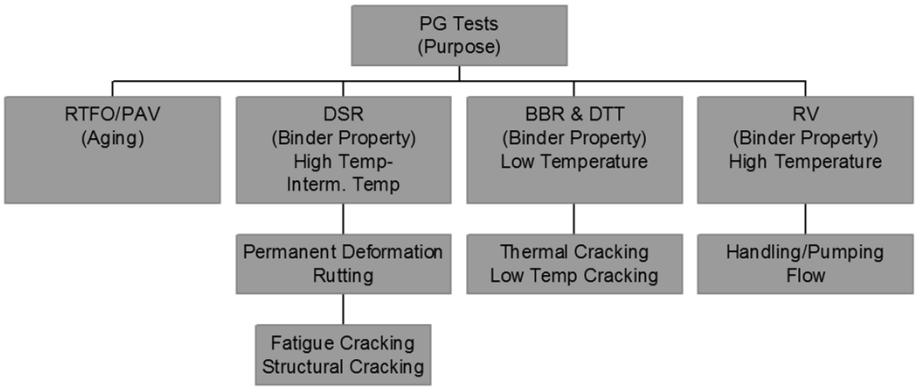
Asphalt Binder

- PG Binder Specifications
  - **P**erformance **G**raded Asphalt Cement/Asphalt Cement Modified Binder Specifications
- Example: **PG 58-28**
  - 58 ~~ 58 deg. C. = 7 day High Temp
  - (-28)~~ -28 deg. C. = 1 day Low Temp
- Rule of 90

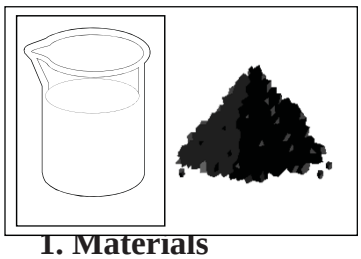
Why PG?

- Old Specifications Did Not Address Pavement Operating Conditions
  - Penetration Graded
  - Viscosity Graded
  - AASHO Road Test
- Market Changed
  - Refinery's Goals are to address Gasoline/Avjet production, not asphalt cement production
  - Oil Embargo/Market Volatility
- Rutting/High Temperature vs. Thermal Cracking/Low Temperature
- Simulate Aging~~Air & Temperature Cycles-Pavement Performance
- Develop Binder for Location, Use, Operating Conditions, and Mix Type
- PG Tests

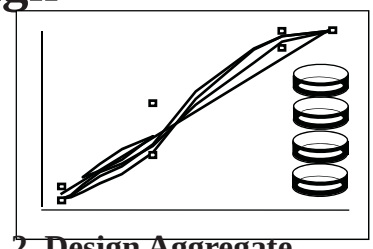
PG Tests



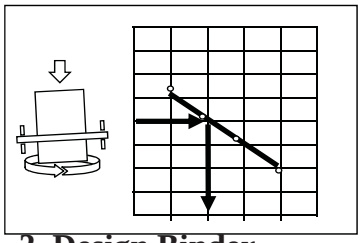
4 Steps of Superpave Mix Design



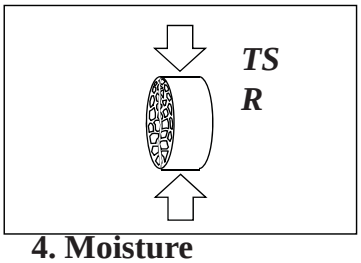
1. Materials Selection



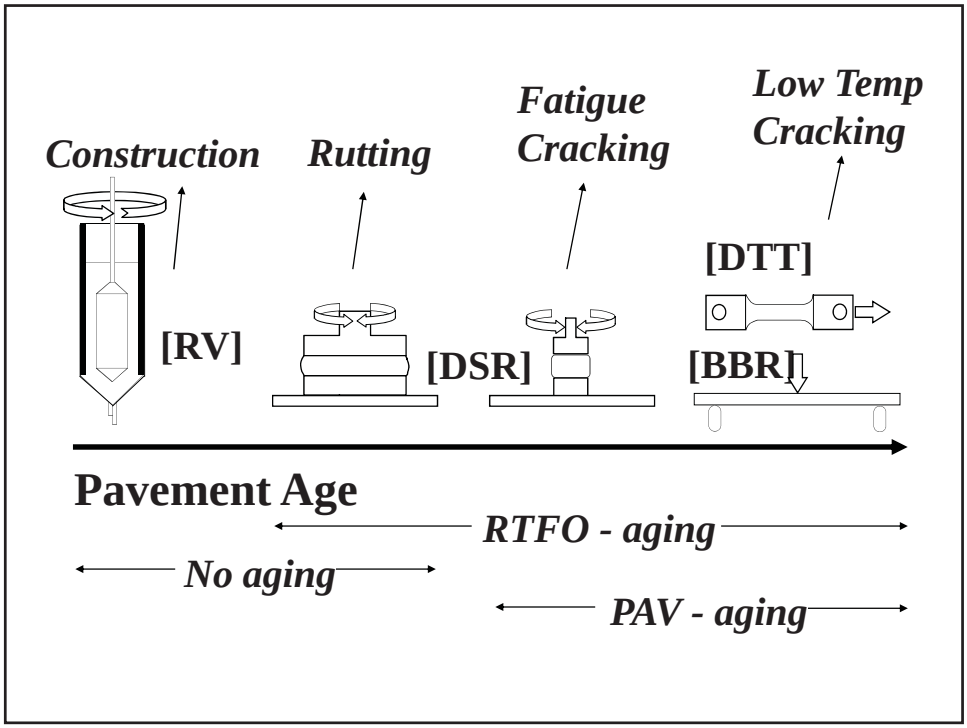
2. Design Aggregate Structure



3. Design Binder Content

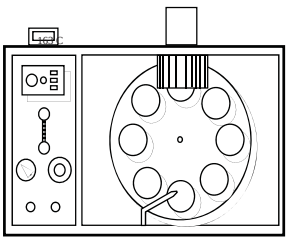


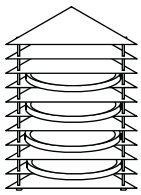
4. Moisture Sensitivity



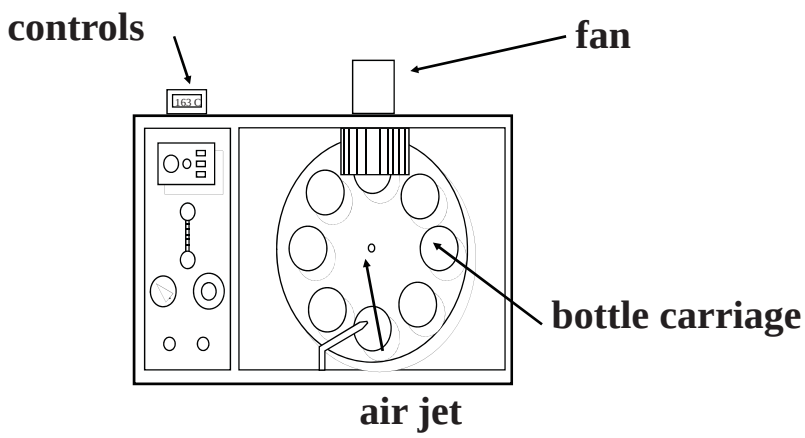
Binder Aging Methods

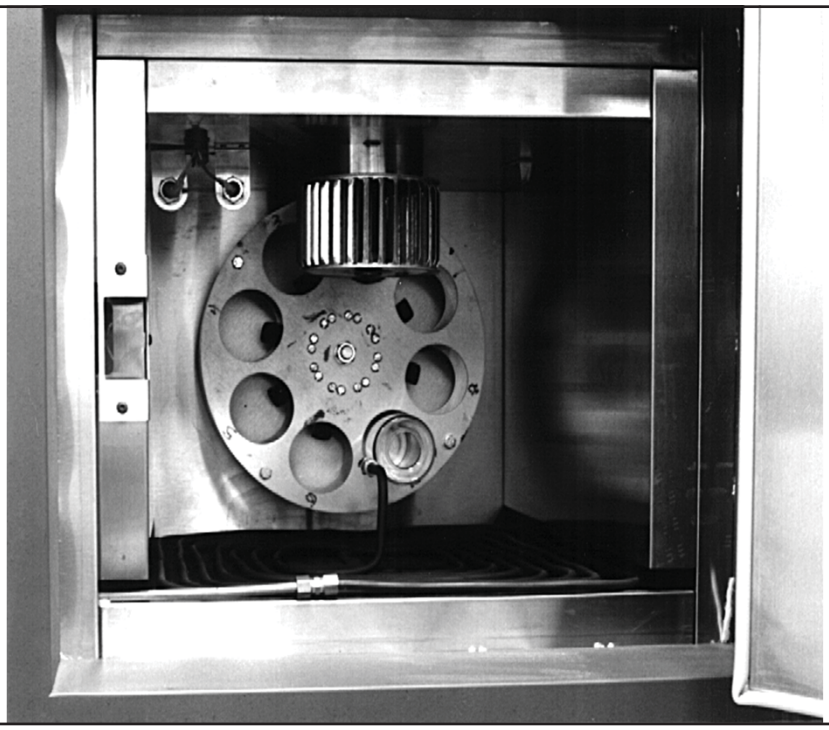
- Rolling Thin Film Oven (RTFO)
  - simulates construction aging
- Pressure Aging Vessel (PAV)
  - simulates long-term pavement aging



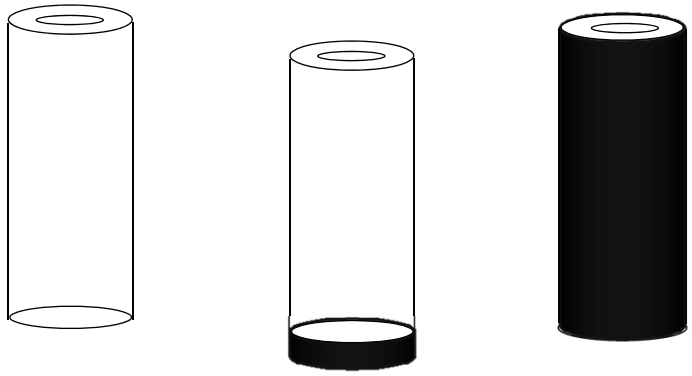


Rolling Thin Film Oven





RTFO Binder Sample



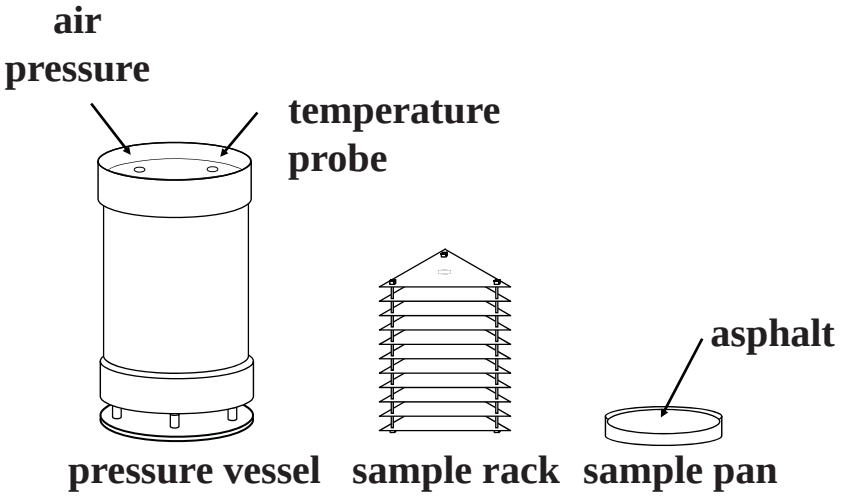
Clean Bottle Before Loading | **After Loading** | **Coated Bottle After Testing**

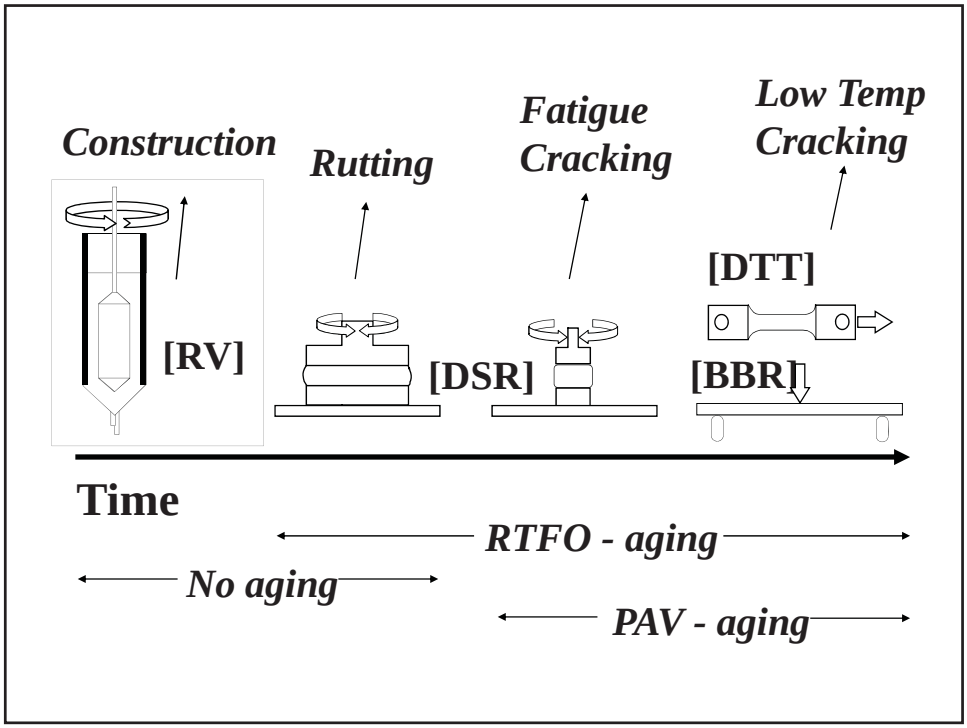
Specification Requirement

- Mass Loss after RTFO > ***Not New***

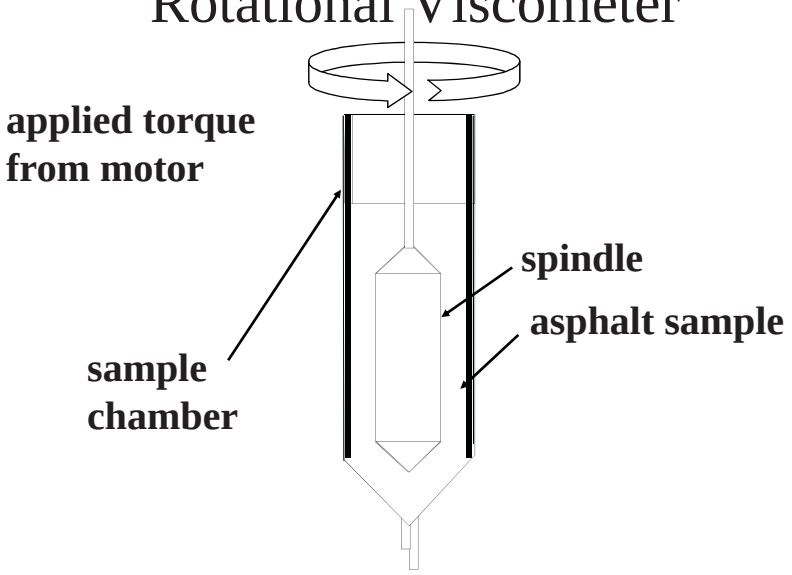
$$\textbf{Mass Loss (\%)} = \frac{\textbf{Original Mass - Aged Mass}}{\textbf{Original Mass}} \textbf{ x 100\%}$$

Pressure Aging Vessel

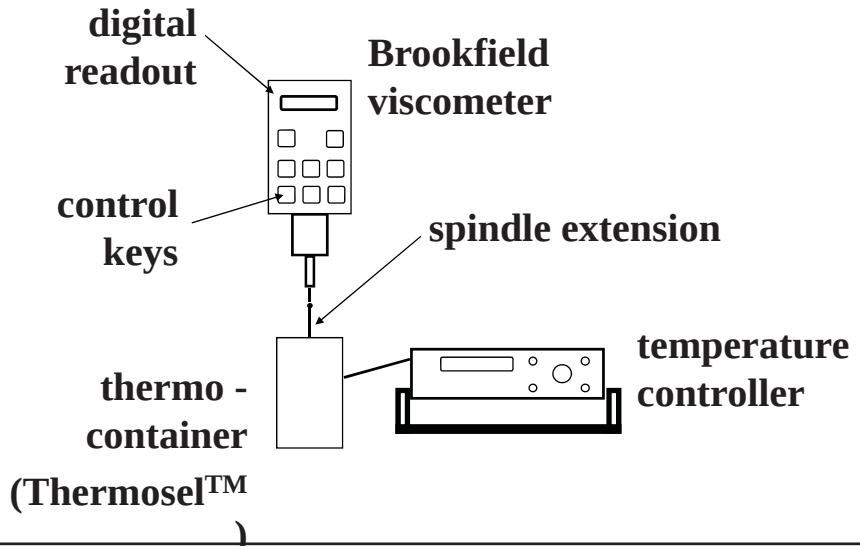


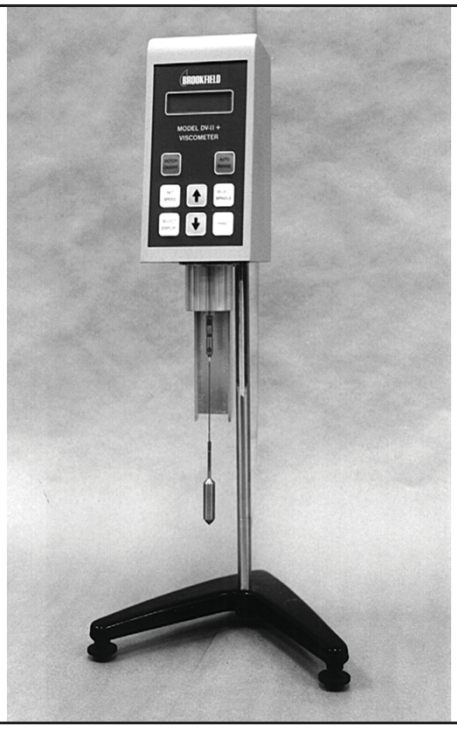


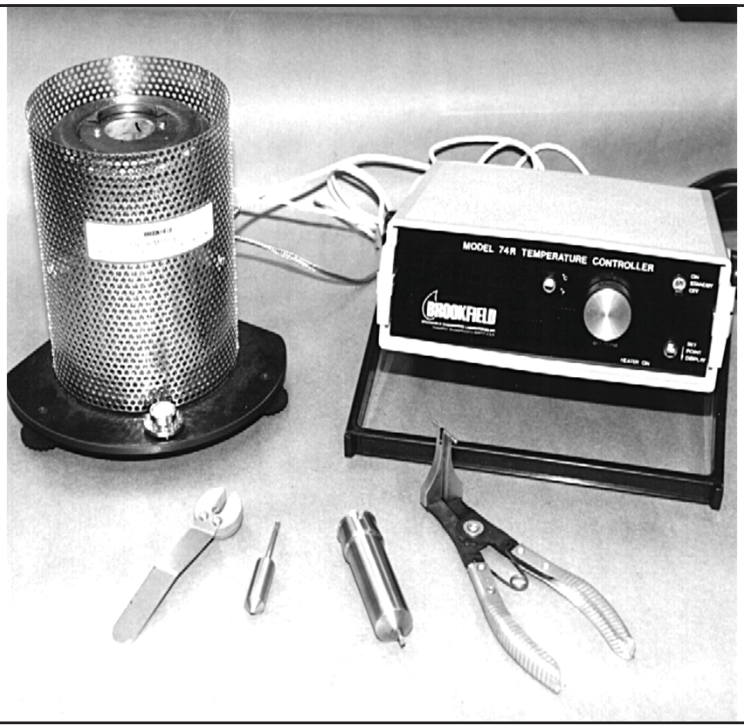
Rotational Viscometer

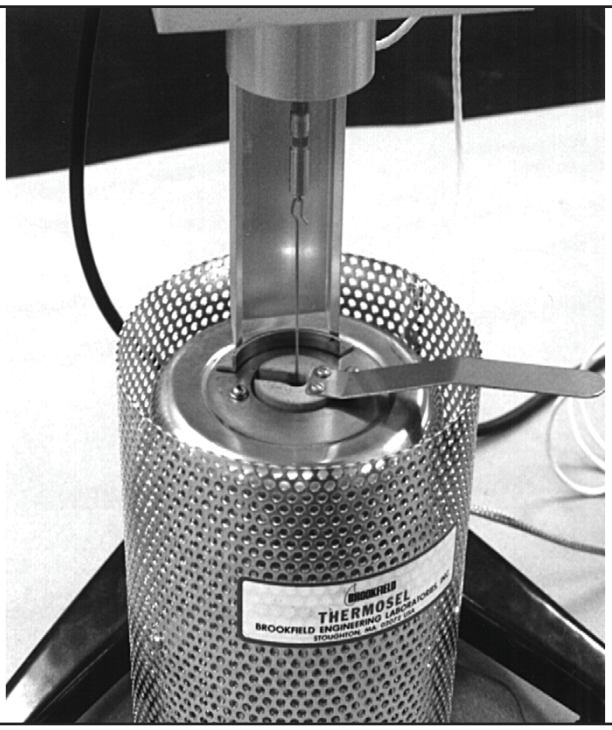


RV Test Equipment






MODEL 74R TEMPERATURE CONTROLLER
BROOKFIELD


BROOKFIELD
THERMOSEL
BROOKFIELD ENGINEERING LABORATORIES INC.

<u>4 Options</u>

percent torque : % 6.0

shear rate (1/sec) : SR 6.8

shear stress (dynes/cm^2) : SS 25.5

viscosity

spindle number

cP 375 SP21
20RPM 135.0°C

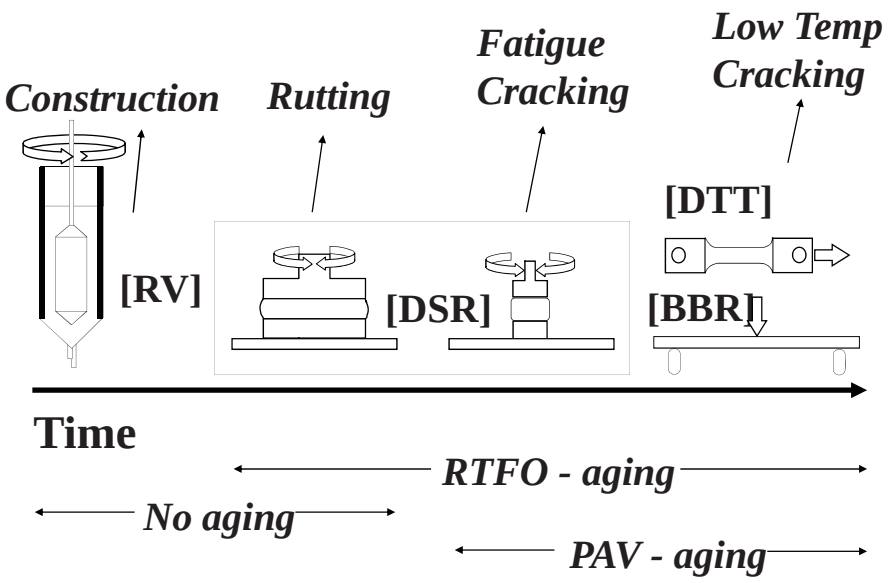
motor speed

temperature

RV Test Data

- Determine
  - viscosity at 135 °C
  - viscosity at 165 °C
- Purpose
  - check for handling and pumping
  - develop temp/vis relationship

PG Spec



DSR Test Equipment

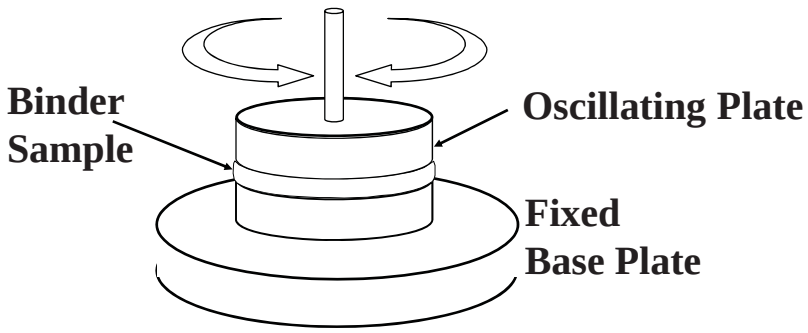
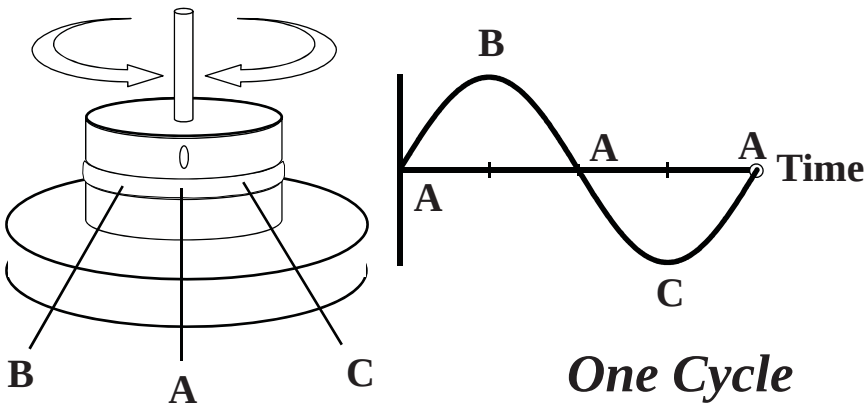
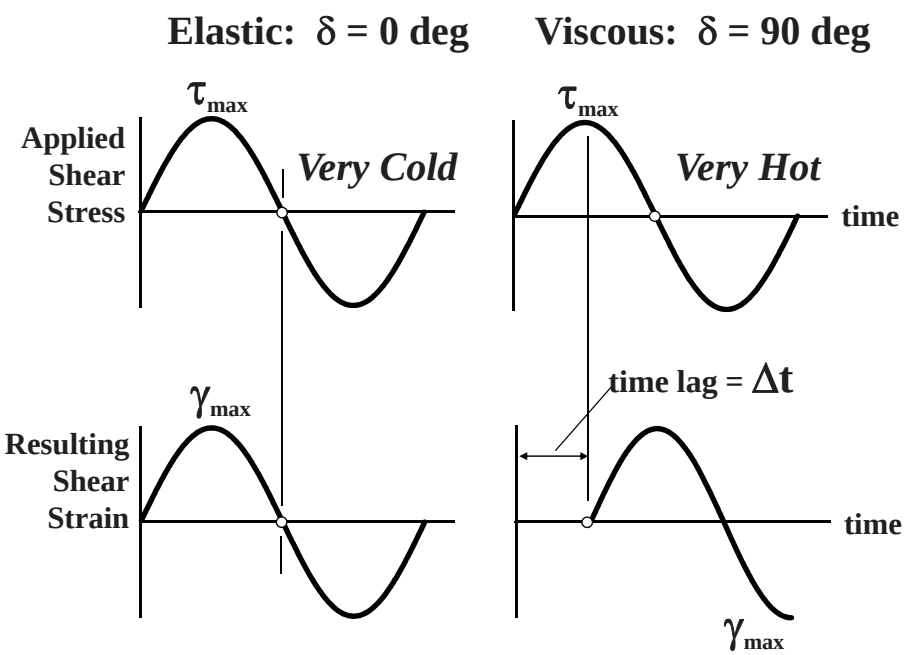
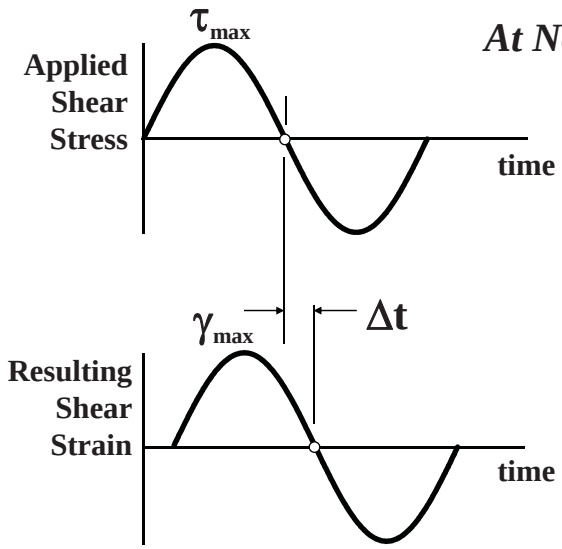


Plate Movement





Viscoelastic: $0 < \delta < 90^{o}$



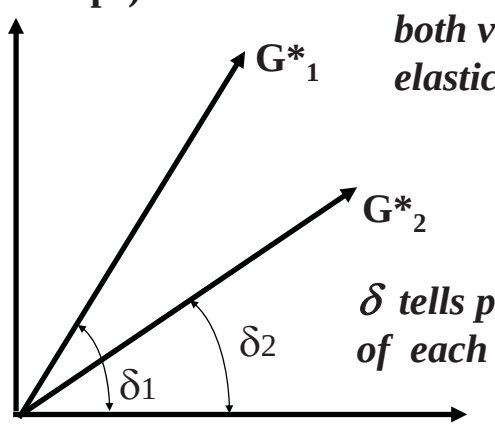
At Normal Temperatures

$$G^* = \frac{\tau_{max}}{\gamma_{max}}$$

$$\Delta t \Rightarrow \delta$$

Typical δ Values
- *Steel = 0*
- *Water = 90*
- *Asphalt = 60 - 85*

Viscous Behavior (High Temps)

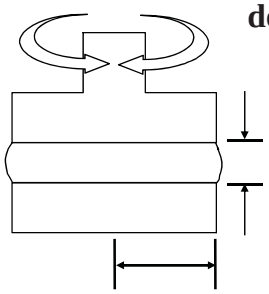


*G * includes both viscous and elastic behavior*

δ tells proportion of each

Elastic Behavior (Low Temps)

Shear Stress (τ) and Shear Strain (γ)

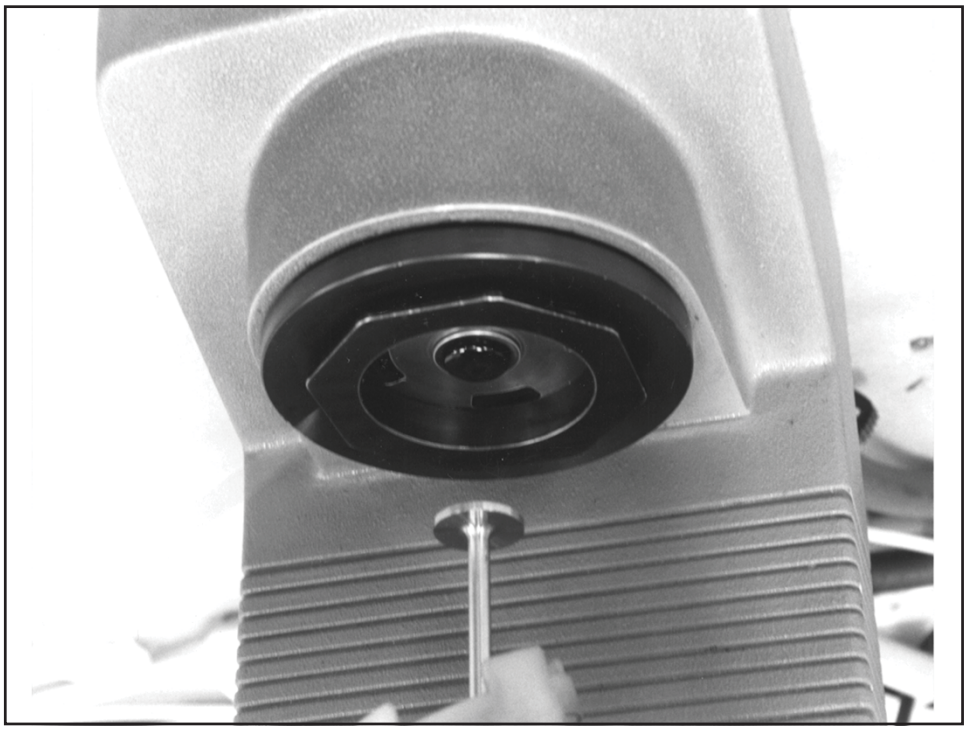


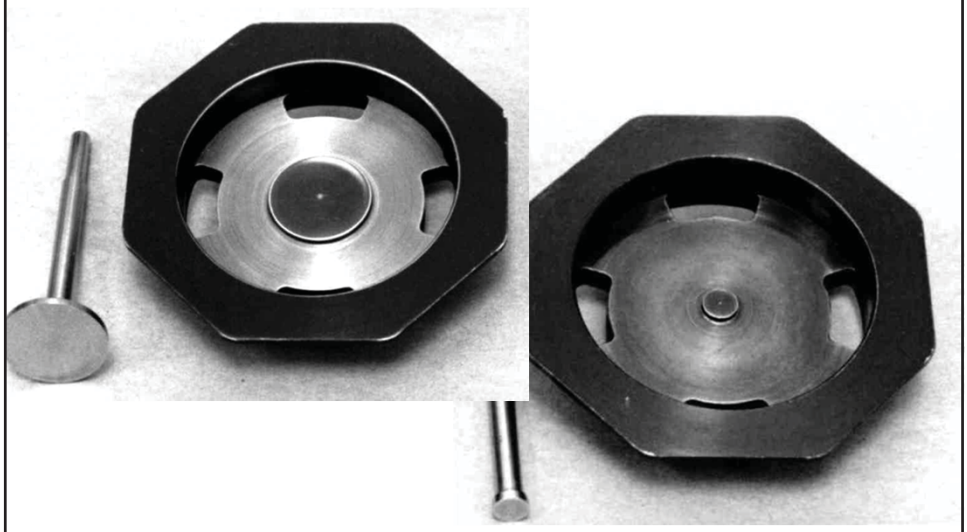
Critical

$$\tau = \frac{2\,T}{\pi\, r^3}$$

$$\gamma = \frac{\Theta\, r}{h}$$

$$G^* = \frac{\tau_{max}}{\gamma_{max}}$$



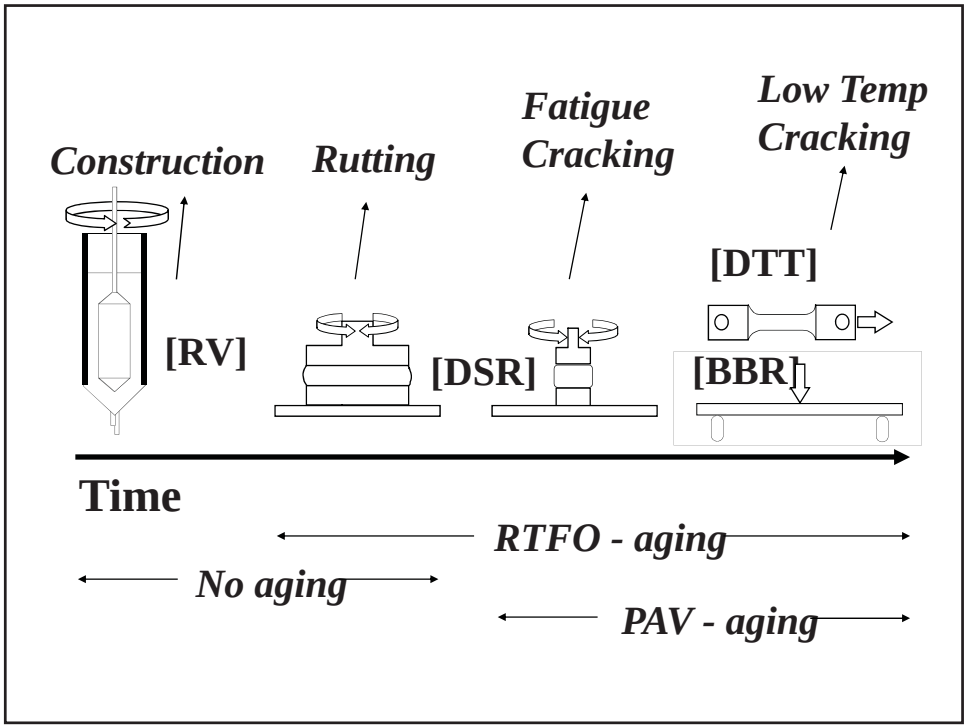


DSR Test Data

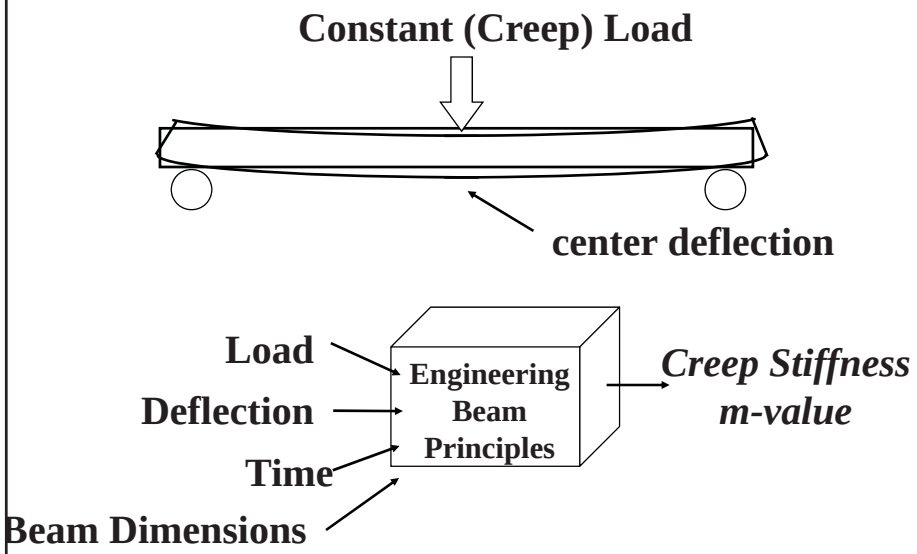
- Rutting
  - G*/ sin δ
  - High temperature stiffness
  - Unaged and RTFO-aged
- Fatigue Cracking
  - G* sin δ
  - Intermediate temperature stiffness
  - PAV-aged

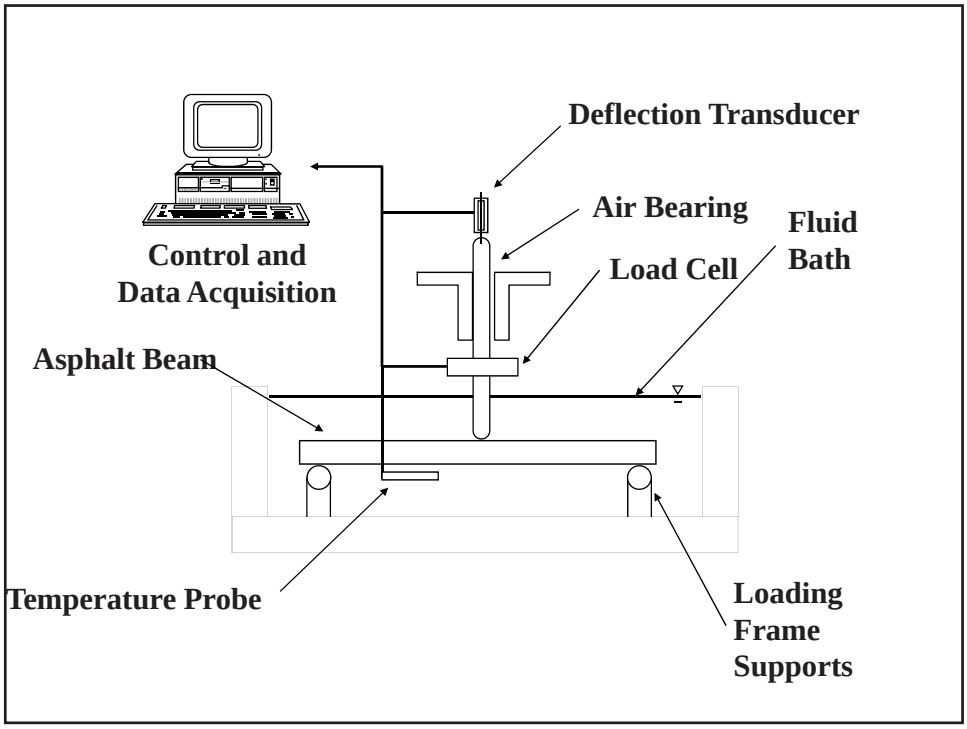
PG Spec

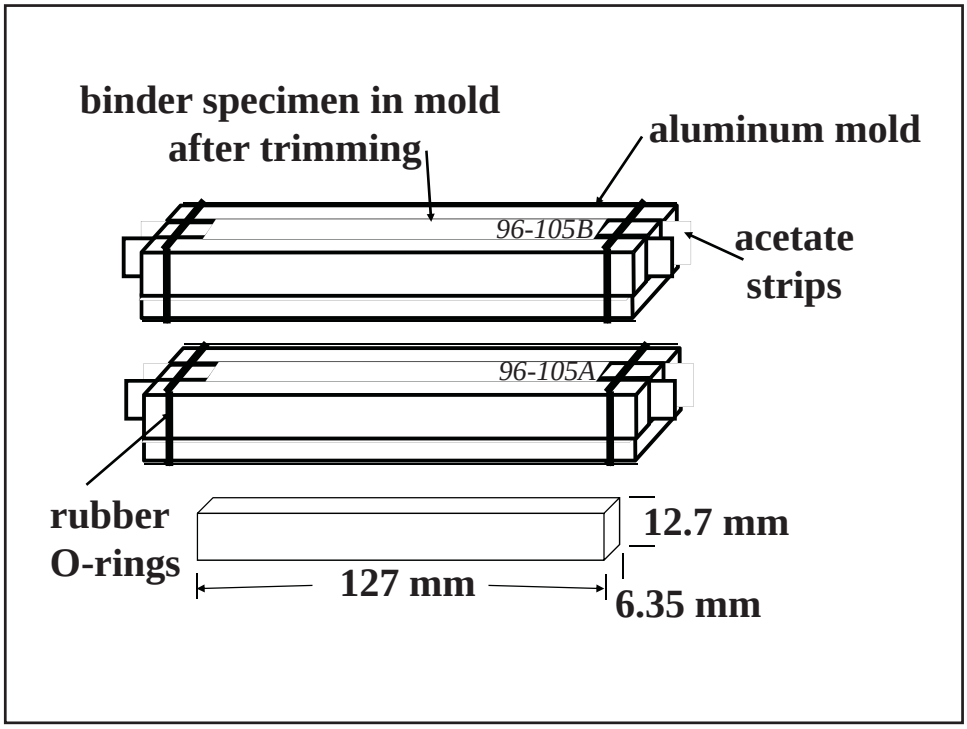
PG Spec

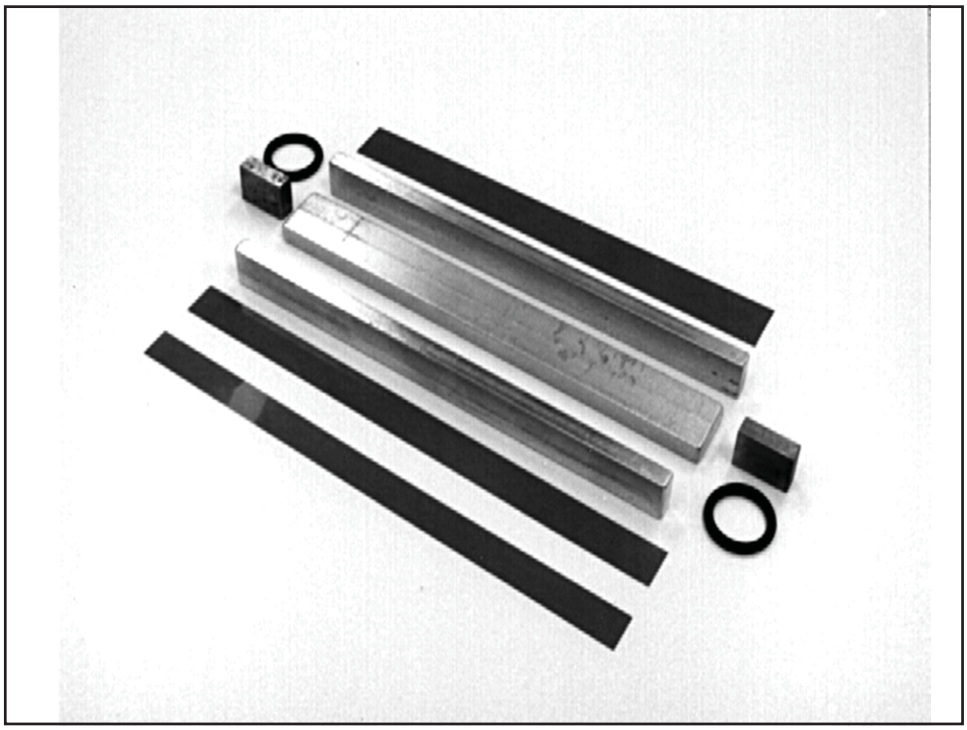


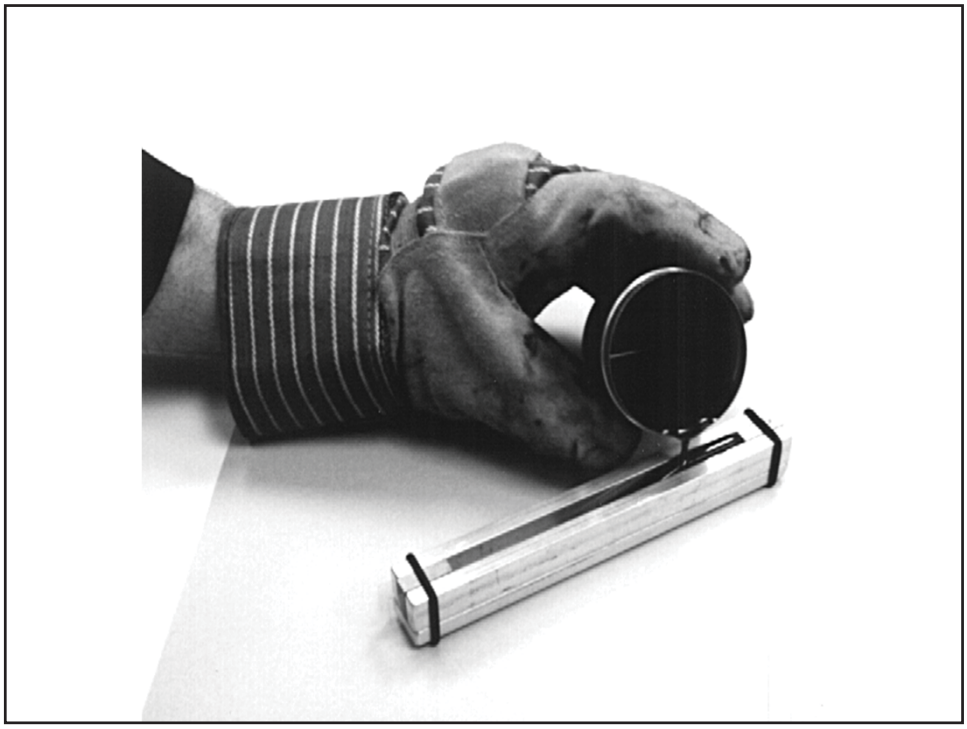
Bending Beam Rheometer

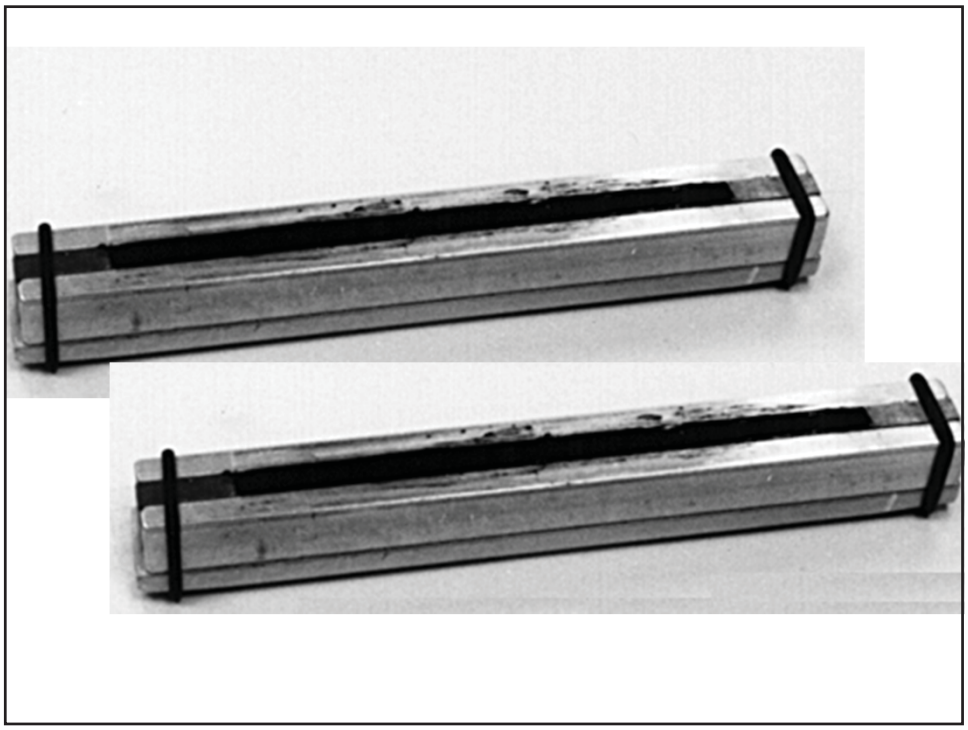


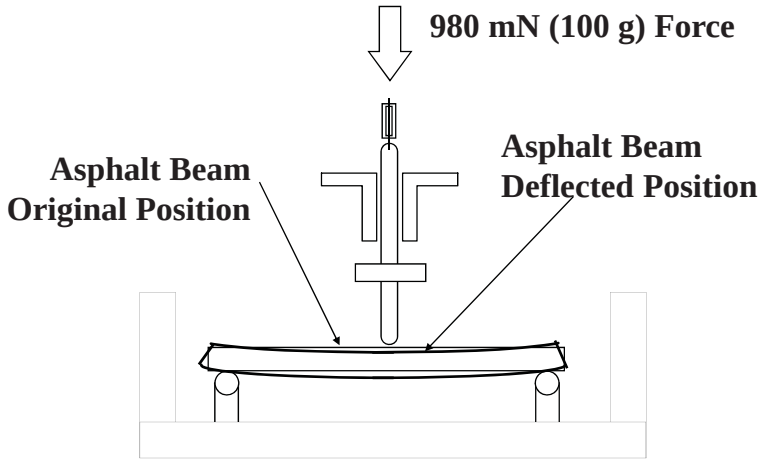

Deflection Transducer
Air Bearing
Fluid Bath
Load Cell
Control and Data Acquisition
Asphalt Beam
Temperature Probe
Loading Frame Supports

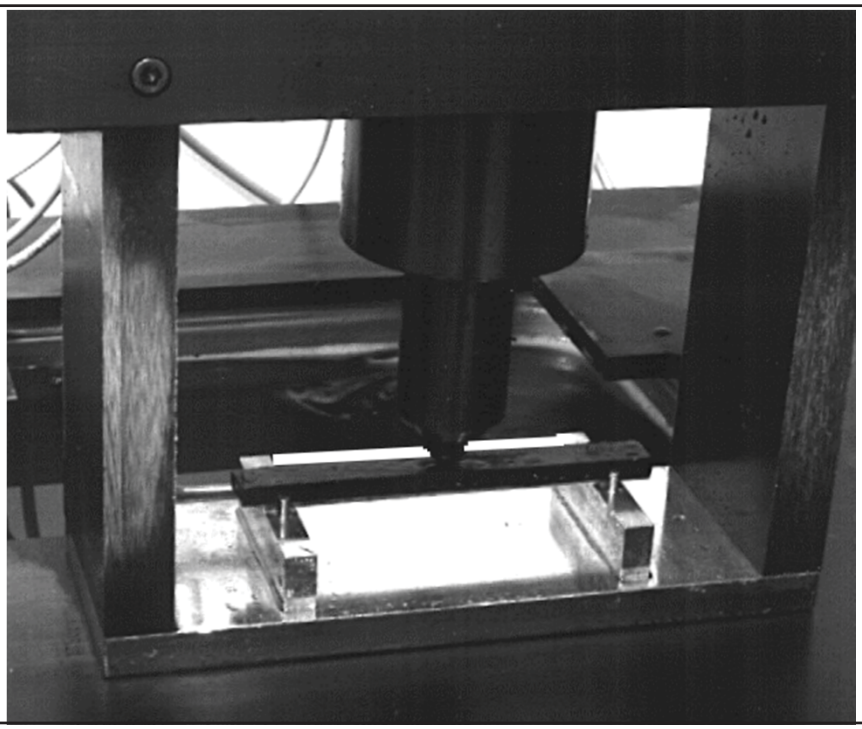

binder specimen in mold
after trimming
aluminum mold
96-105B
acetate
strips
96-105A
rubber
O-rings
12.7 mm
127 mm
6.35 mm



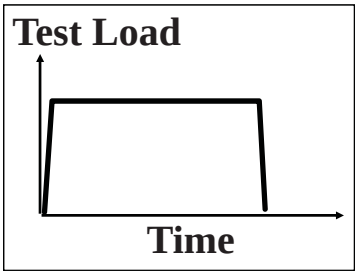


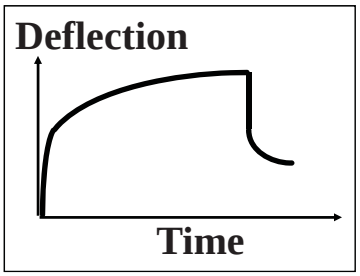



980 mN (100 g) Force
Asphalt Beam
Original Position
Asphalt Beam
Deflected Position



Overview of BBR Procedure





BBR Data - Stiffness

creep stiffness at t = 60 sec

load = 100 g

length between supports

$$S(t) = \frac{PL^3}{4bh^3\,\Delta(t)}$$

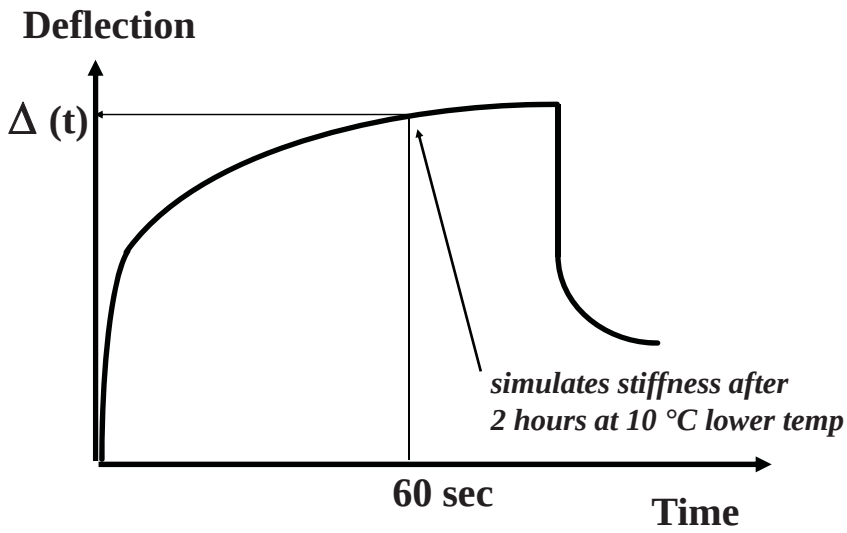
PG Spec

beam width = 12.7 mm

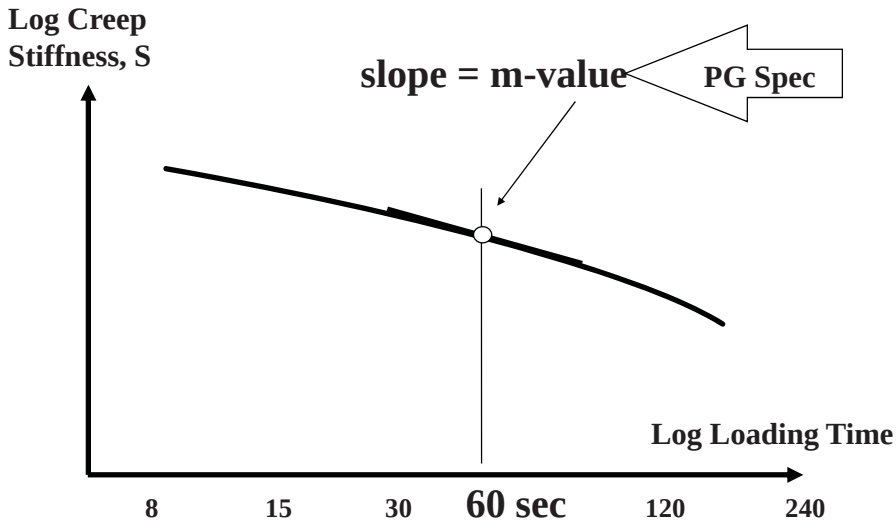
beam thickness = 6.35 mm

deflection at t = 60 sec

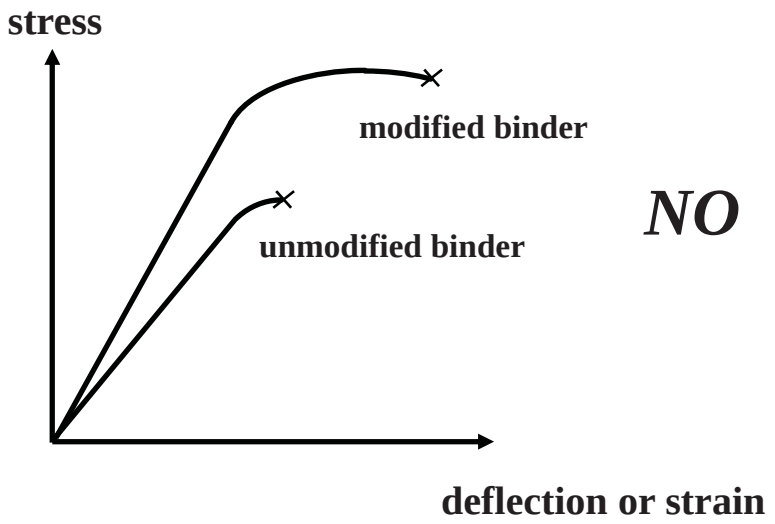
BBR Data - Stiffness



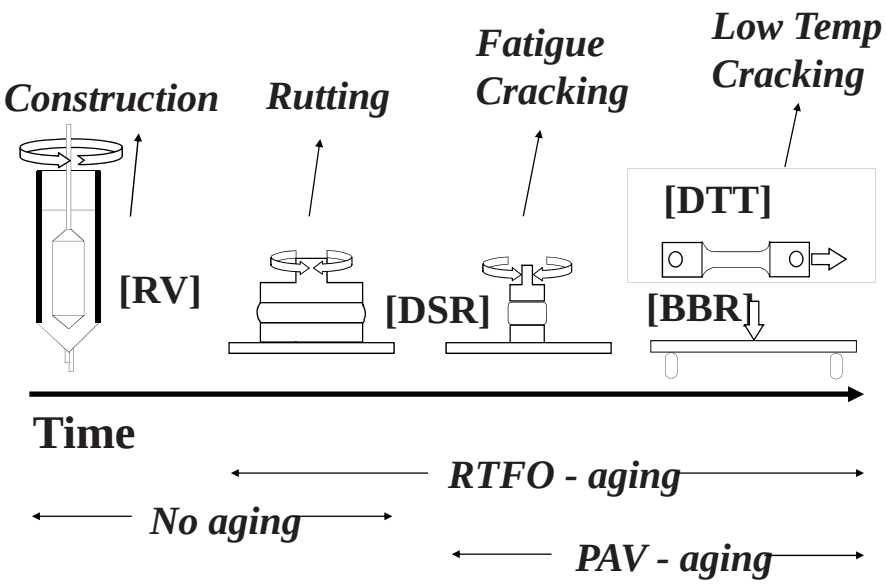
BBR Data - "Relaxation"



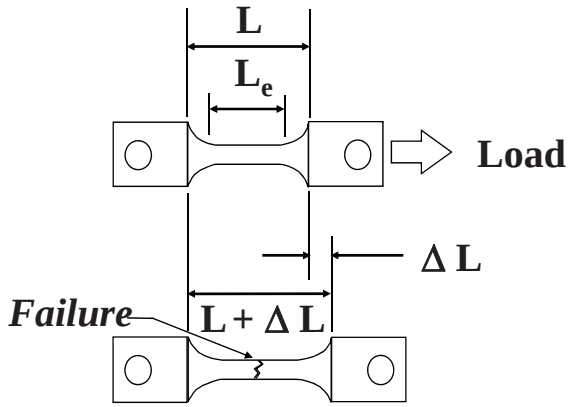
Is Stiffness enough ?



NO

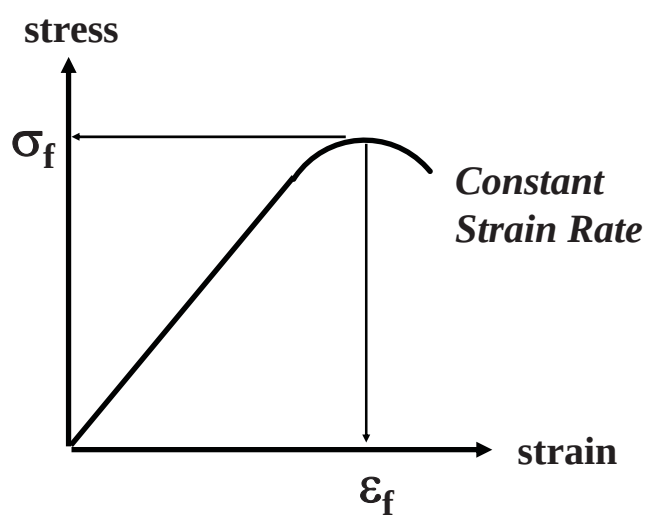


Direct Tension Tester

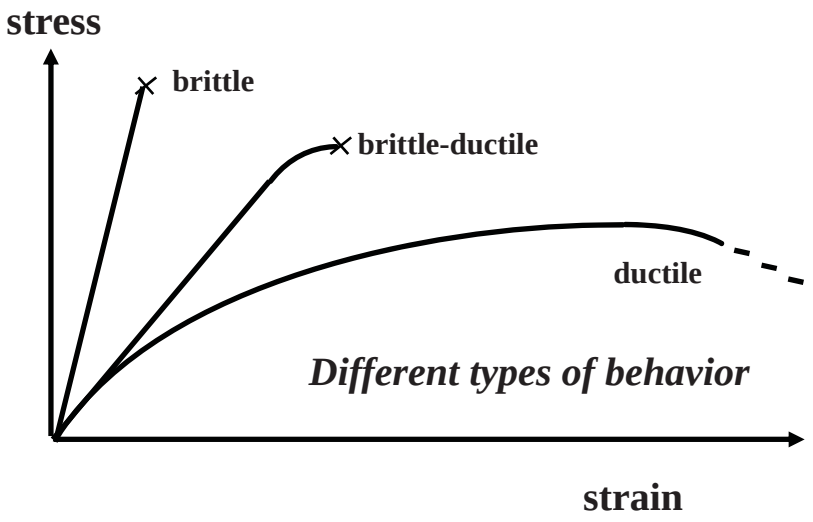


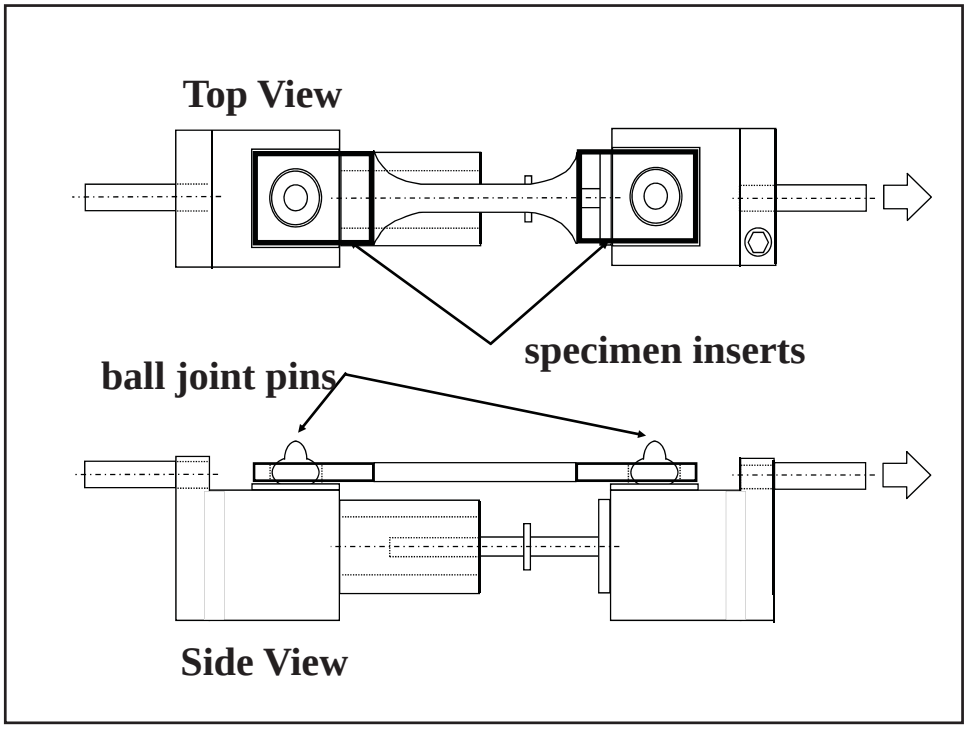
$$\text{failure strain } (\varepsilon_f) = \frac{\text{change in length } (\Delta L)}{\text{effective gauge length } L_e}$$

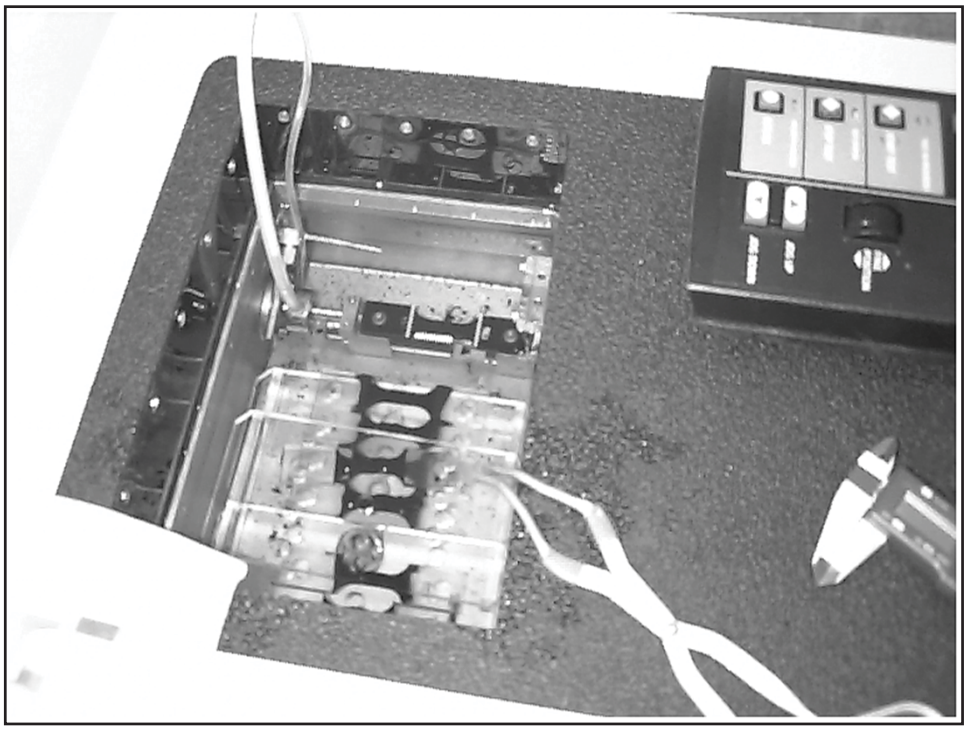
DTT Data

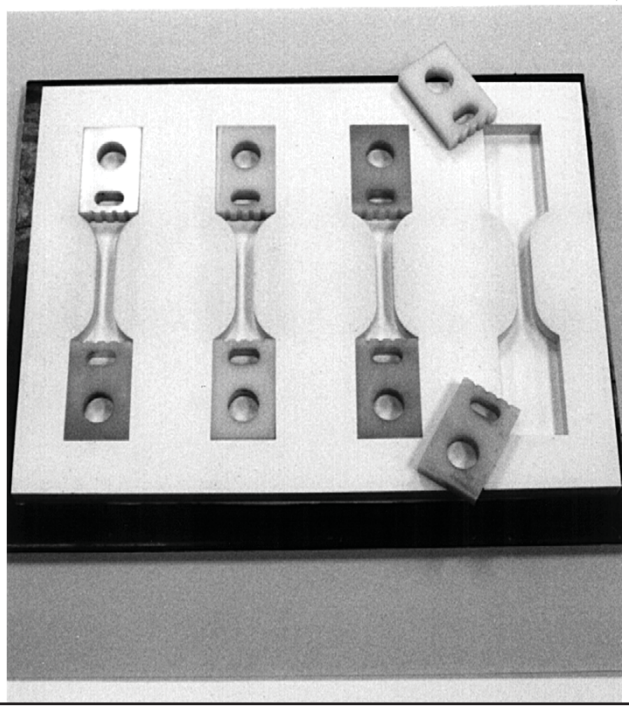


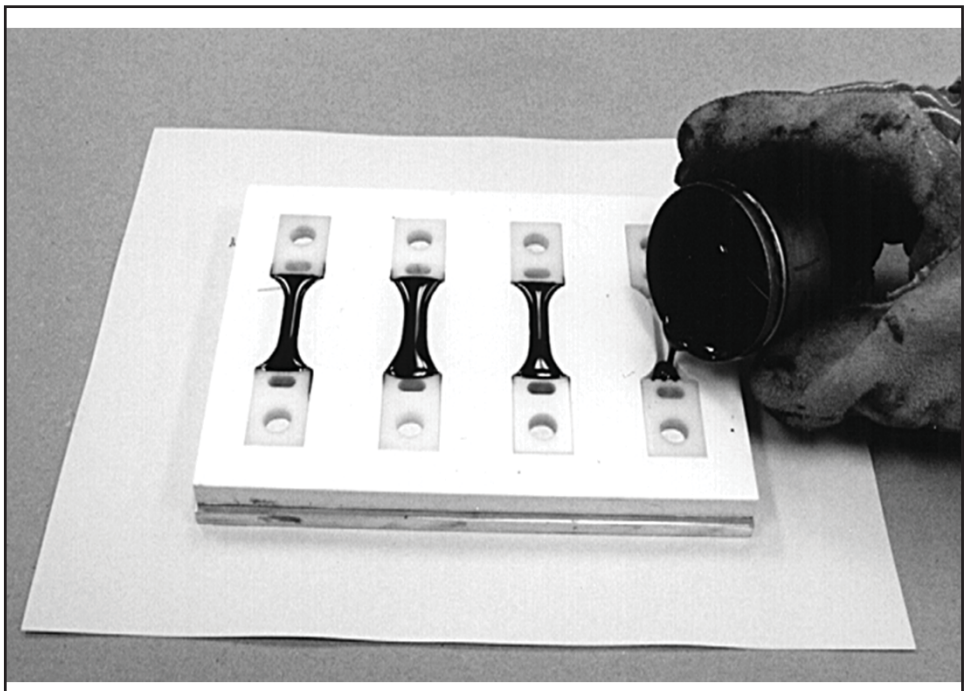
Different Binders or Temps




Top View
specimen inserts
ball joint pins
Side View



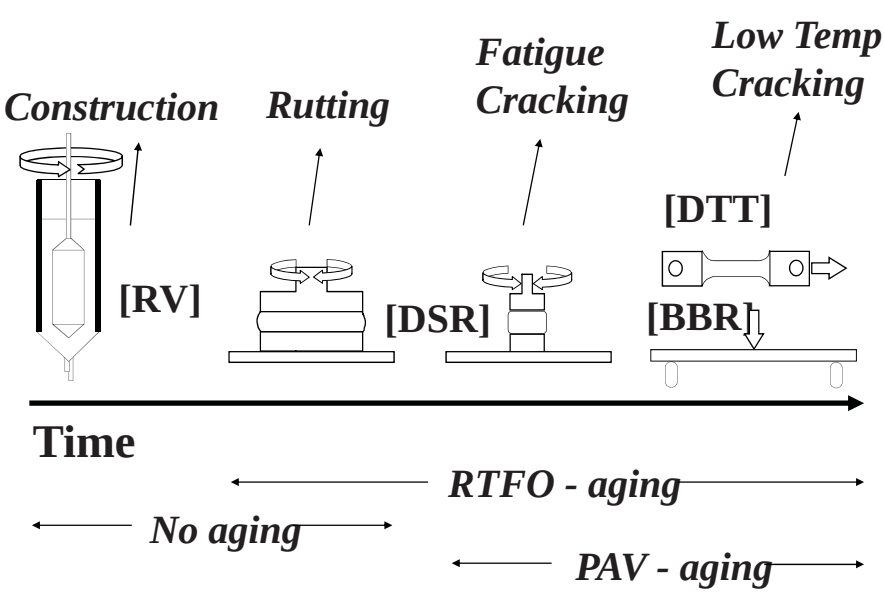




DTT Test Data

- Report
  - strain at peak stress
  - stress at failure
- Purpose
  - low temperature capacity to stretch

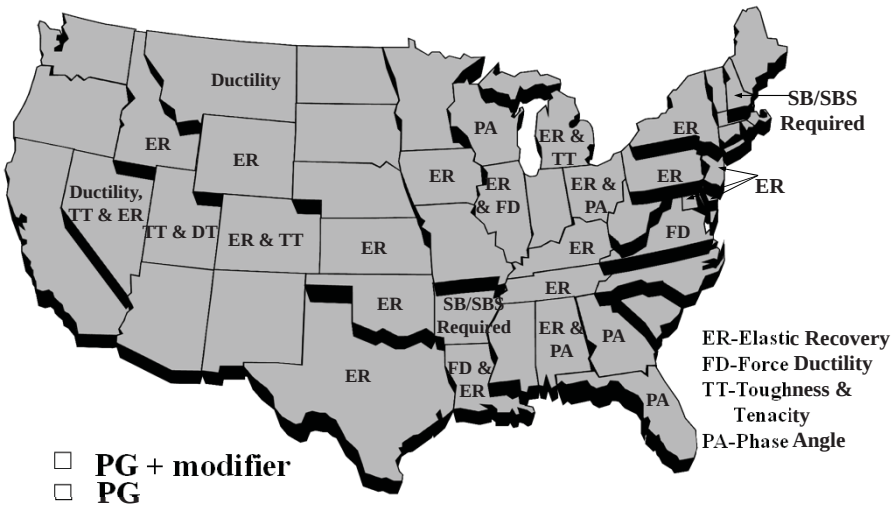
PG Spec



What Does It Mean to ND?

- ND – Typical PG Binder is PG 58-28
- Upgraded PG 64-28 or PG 58-34 for High Service, Heavy Loading, Special Operating Conditions
- PG 64-28~~~AC 20
- # Loads, Type of Loads, Rate of Loading & Time of Year all Impact Service Rating…..Design
- DOT Mixes/Commercial Plants…Availability of Binder at Cost Effective Rate

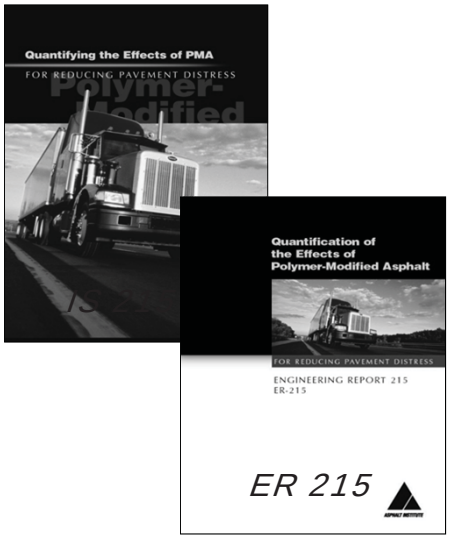
State DOT's Specifying Polymer PG (PG+)



Using PMA From A Design Engineer's Perspective

- PMA is One of Many Tools Available
- Performance Benefits Acknowledged
  - Lab and Field
- The Big Question:
  - How Do I Quantify the Benefits?

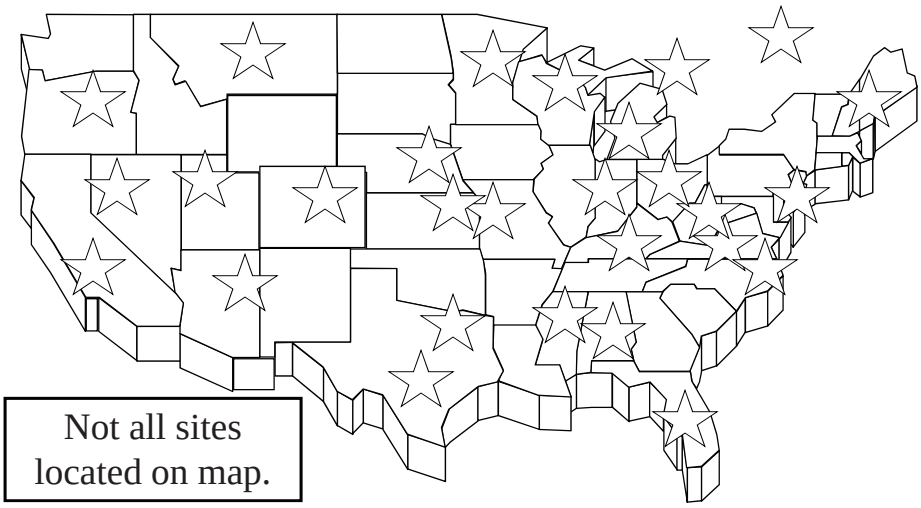
Quantifying the Effects of PMA for Reducing Pavement Distress



This study (published in Feb 2005) uses national field data to determine enhanced service life of pavements containing polymer modified binders versus conventional binders. The data is from a variety of climates and traffic volumes within North America.

Locations of State and Federal Agency Test Sections

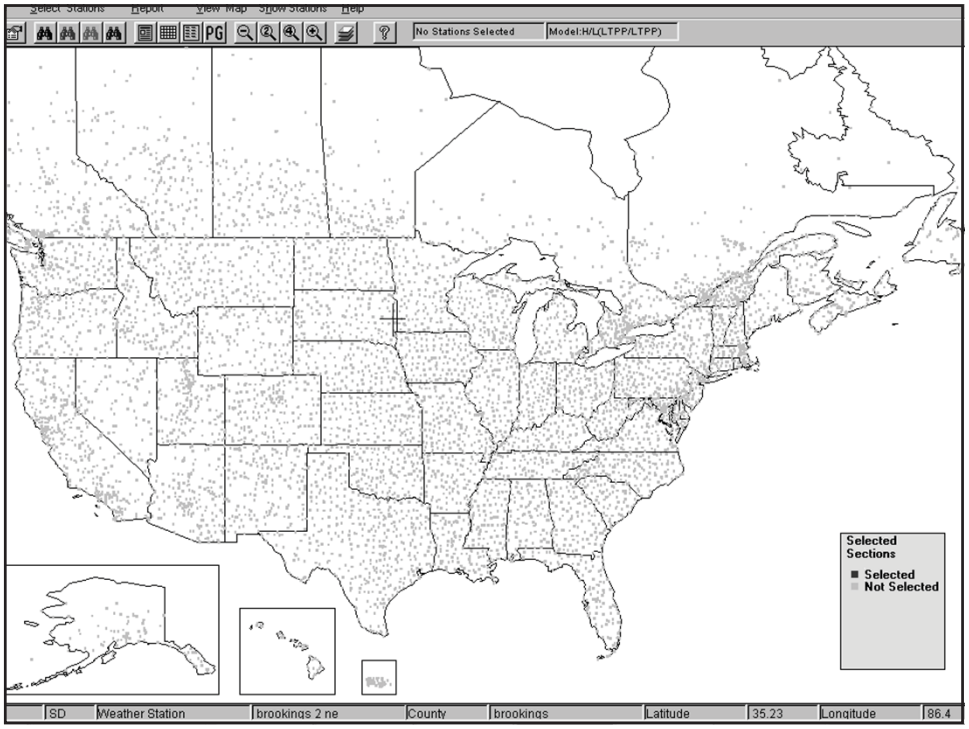
- PMA and Unmodified Companion

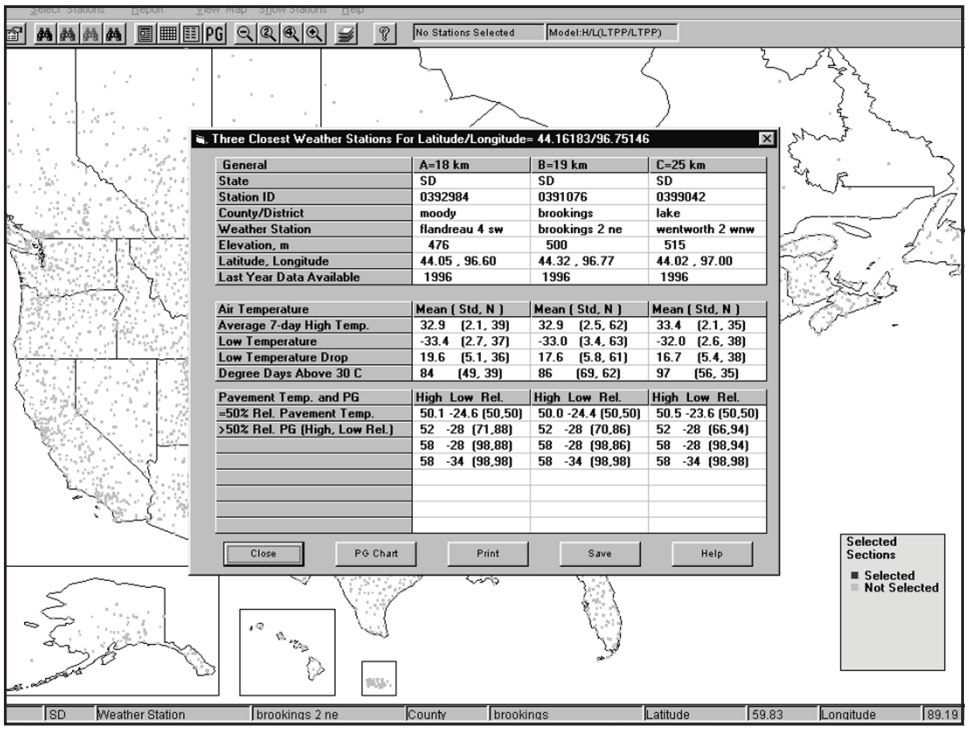


Not all sites located on map.

Superpave-Binder

- LTPP Bind Example

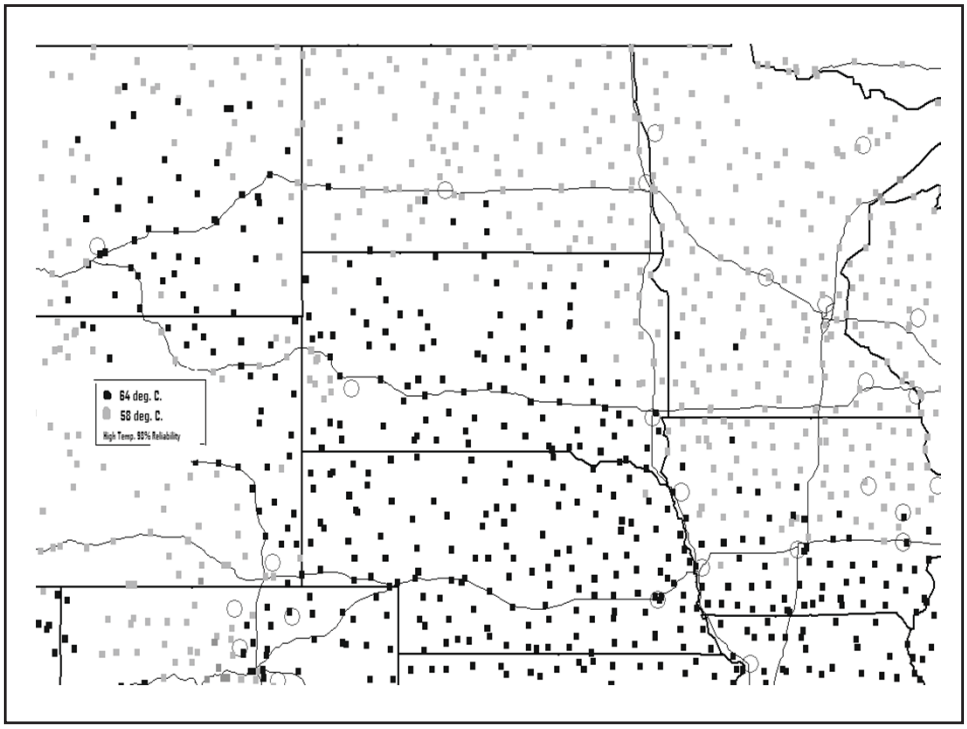


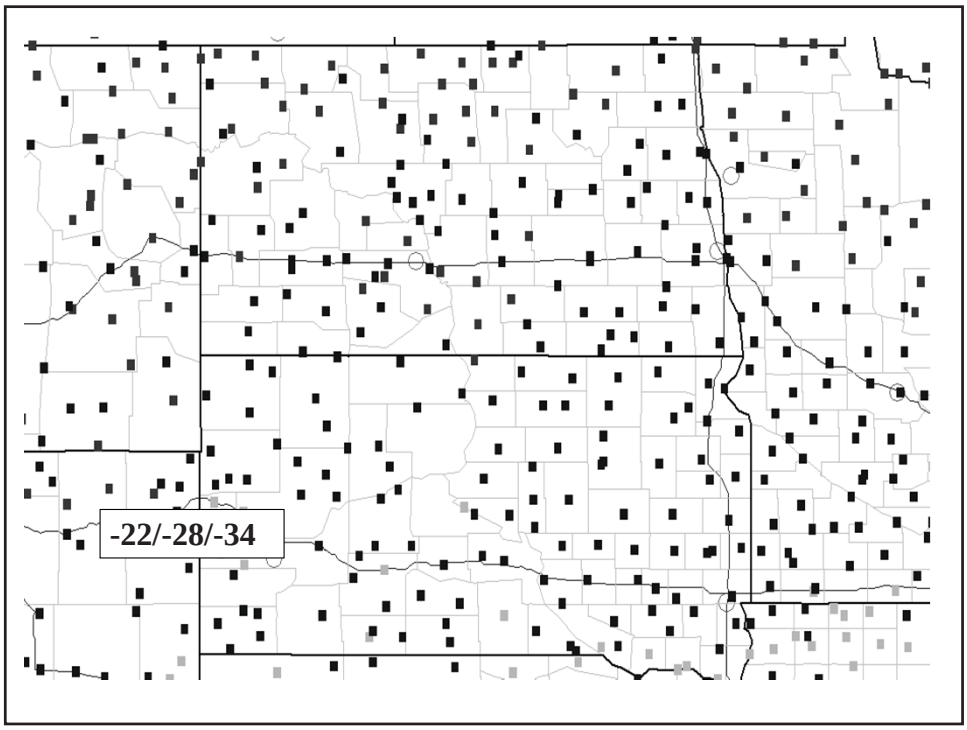


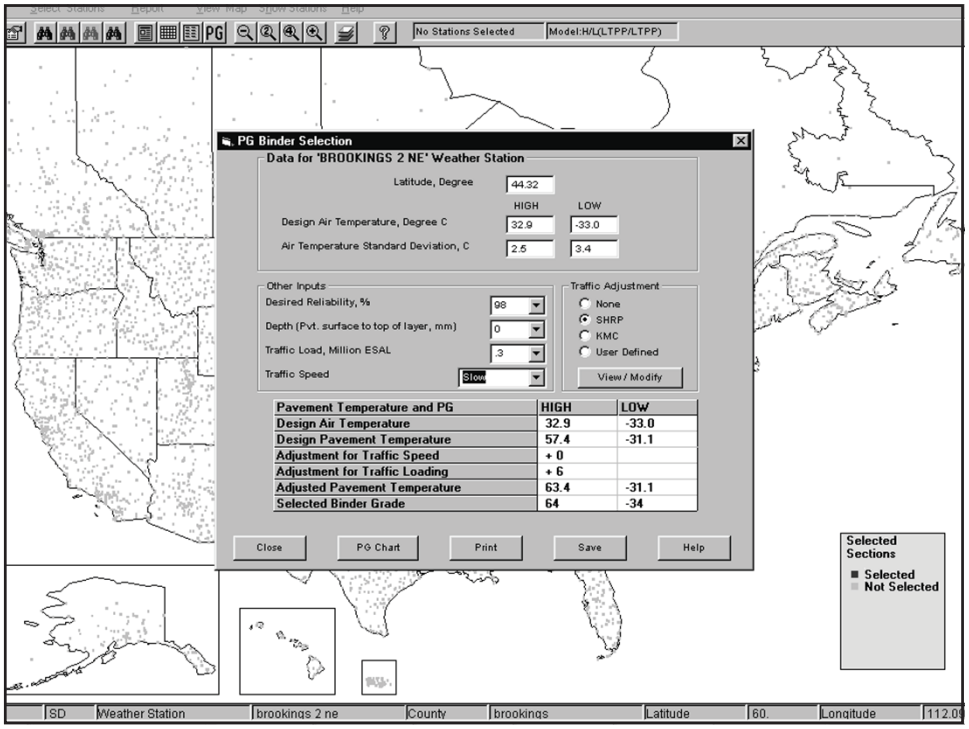
General	A=18 km	B=19 km	C=25 km
State	SD	SD	SD
Station ID	0392984	0391076	0399042
County/District	moody	brookings	lake
Weather Station	flandreau 4 sw	brookings 2 ne	wentworth 2 wnw
Elevation, m	476	500	515
Latitude, Longitude	44.05 , 96.60	44.32 , 96.77	44.02 , 97.00
Last Year Data Available	1996	1996	1996

Air Temperature	Mean (Std, N)	Mean (Std, N)	Mean (Std, N)
Average 7-day High Temp.	32.9 (2.1, 39)	32.9 (2.5, 62)	33.4 (2.1, 35)
Low Temperature	-33.4 (2.7, 37)	-33.0 (3.4, 63)	-32.0 (2.6, 38)
Low Temperature Drop	19.6 (5.1, 36)	17.6 (5.8, 61)	16.7 (5.4, 38)
Degree Days Above 30 C	84 (49, 39)	86 (69, 62)	97 (56, 35)

Pavement Temp. and PG	High Low Rel.	High Low Rel.	High Low Rel.
=50% Rel. Pavement Temp.	50.1 -24.6 (50,50)	50.0 -24.4 (50,50)	50.5 -23.6 (50,50)
>50% Rel. PG (High, Low Rel.)	52 -28 (71,88)	52 -28 (70,86)	52 -28 (66,94)
	58 -28 (98,88)	58 -28 (98,86)	58 -28 (98,94)
	58 -34 (98,98)	58 -34 (98,98)	58 -34 (98,98)


64 deg. C.
58 deg. C.
High Temp. 95% Reliability


-22/-28/-34




```
LTPPBind V2.1 Three closest weather Stations Report:  (Date 10/18/02 )
For Latitude/Longitude=  47.87481 / 97.19178


                                A=9  km                  B=10  km                 C=30  km

State                           ND                       ND                       ND
Station ID                      0323616                  0323621                  0325013
County                          GRAND FORKS              GRAND FORKS              GRAND FORKS
Weather Station                 GRAND FORKS MUNI AP      GRAND FORKS UNIV         LARIMORE
Elevation, m                    258                      253                      345
Latitude/Longitude              47.95/97.17              47.93/97.08              47.92/97.63
Last Year Data Available        1996                     1996                     1996

Low Temp. Mean (Std, N)          -34.3 (2.4,43)           -33.9 (2.9,49)           -34.7 (2.9,23)
High 7-day Average Mean (Std, N)  31.9 (1.7,45)            32.4 (1.7,45)            31.3 (2.1,21)
Low Temp. Drop Mean (Std, N)      13.6 (4.8,42)            14.8 (4.5,49)            15.8 (6.0,23)
Degree Days Over 30 C (Std, N)       59 (38,45)               67 (39,45)               44 (30,21)

Using HT/LT Model:LTPP/LTPP
50% Reliability Pavement Temp.  48.4 -26.7 (50,50)       48.8 -26.4 (50,50)       48.0 -27.0 (50,50)
>50% Rel. PG (High, Low Rel.)   52   -28   (86,68)       52   -28   (83,70)       52   -28   (88,63)
                                52   -34   (86,98)       52   -34   (83,98)       52   -34   (88,98)
                                58   -34   (98,98)       58   -34   (98,98)       58   -34   (98,98)
```

LTPPBind V2.1 PG Binder Selection Report (Date: 10/18/02)

Data for 'GRAND FORKS MUNI AP' Weather Station

Latitude, Degree	47.95	
Depth to Surface of Layer, mm	0	
Desired Reliability, Percent	98	
Traffic Loading, Million ESAL	.3	
Traffic Speed	Standing	
Method For Adjusting for Traffic	SHRP	
Pavement Temperature and PG	HIGH	LOW
Design Air Temperature	31.9	-34.3
Design Air Temp. Std. Dev.	1.7	2.4
Using HT/LT Model:LTPP/LTPP	HIGH	LOW
Design Pavement Temperature	55.2	-32.3
Adjustment for Traffic Loading	+ 0	
Adjustment for Traffic Speed	+ 12	
Adjusted Pavement Temperature	67.2	-32.3
Selected Binder Grade	70	-34

LTPPBind V2.1 PG Binder Selection Report (Date: 10/18/02)

Data for 'GRAND FORKS MUNI AP' Weather Station

Latitude, Degree	47.95	
Depth to Surface of Layer, mm	0	
Desired Reliability, Percent	50	
Traffic Loading, Million ESAL	.3	
Traffic Speed	Standing	
Method For Adjusting for Traffic	SHRP	
Pavement Temperature and PG	HIGH	LOW
Design Air Temperature	31.9	-34.3
Design Air Temp. Std. Dev.	1.7	2.4
Using HT/LT Model:LTPP/LTPP	HIGH	LOW
Design Pavement Temperature	48.4	-26.7
Adjustment for Traffic Loading	+ 0	
Adjustment for Traffic Speed	+ 12	
Adjusted Pavement Temperature	60.4	-26.7
Selected Binder Grade	64	-28

"In Closing……"

- Model Specifications
- DOT Projects
  - 4.5 Million Tons– Superpave Projects; 2013-2014
  - Binder Selection – Adopted Superpave
  - Marshall Mix Design Fading Away
- ND QC/QA Mixes
  - Aggregate/HMA Costs Very Competitive
  - Better Aggregate=Better Performance in the Right Mix Design
- Increasing Use of High Traffic/High Reliability Grades
  - PG 70-28; PG 64-34

ND QC/QA Asphalt Concrete Mix Controller

Preparation for Mix Design

APPARATUS

- Thermometers: Armored-glass, dial type or digital thermometer with metal stems is recommended. A range of 50° to 400°F (10° to 200°C) with graduations of 5°F (2°C) is required.
- Balances: 20,000-gram capacity, 0.1 gram resolution for mix design and production testing.
- Forced Draft Oven, 350°F (177°C) minimum with controls sensitive to ± 5°F (3°C), minimum size, 7 cu. ft. for production testing or mix design.
- Mixer: Hobart 19 liters with Dough Hook, Model A-200 for Mix Design.
- Safety equipment: insulated gloves, long sleeves, apron, etc.
- Pans of sufficient size for splitting and curing of samples.

General Equipment:

- Scoop or trowel for moving mixture.

NOTE: Experience has shown that a 15 cu. ft. or larger oven may be desirable

Getting an early start

Begin planning for final mix design procedures during the material production stage

Pit Operations and Stockpiling of Aggregate (430.04 C)

Quality Control Samples and Tests during Aggregate Production (FSTM 430):

- Gradation, FAA, LWP, F&E, FF, Sand Equivalent (SFN 9987 Aggregate Sample Worksheet) . For each Aggregate Stockpile:
  - One test per 1000 tons Gradation
  - Average 3 randoms in first 5000 tons LWP, F&E, FF
  - Average 3 randoms in first 5000 tons FAA, SE…if samples pass 1/10000 tons thereafter

Getting an early start (con't)

Pit Operations and Stockpiling of Aggregate (430.04 C)

Quality Control Samples and Tests during Aggregate Production (FSTM 430):

- During 1st week of production of "representative" material:
  - Contractor with Engineer observing obtains 90 lb. sample from each stockpile
  - QC/QA split sample and test bulk (dry) specific gravity, apparent specific gravity and absorption…a second test during production is required
  - Preliminary mix design is prepared and submitted to District Materials Coordinator for Informational Purposes

Aggregate Samples for Mix Design

- Mix design samples will be tested and compared to the stockpile averages to determine if they are representative of the material produced.
- The best mix design samples are those taken from splits of tests conducted during material production.

Aggregate Samples for Mix Design

- The Job Mix Formula (JMF) gradation will be based on the sample submitted for mix design, adjusted to best fit the stockpile averages.
- It is in the best interest of all to assure the mix design samples approximate the average gradation of stockpiles when submitted to the DOT

What is meant by best fit?

- Mix Design specimens will be batched and tested according to the JMF Gradation.
- Aggregate fractions *(materials retained on each sieve)* will be added individually to each specimen batch.
- Coarse sieve materials can be adjusted to exactly match the average of the stockpile tests.
- Fine sieves or "Pan" material will be added all at once.

Example

	Stockpile Gradations				Mix Design Gradations			
US	Agg.1	Agg.2	Agg.3	Agg.4	Agg.1	Agg.2	Agg.3	Agg.4
1"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3/4"	92.0	100.0	100.0	100.0	92.0	100.0	100.0	100.0
1/2"	50.9	100.0	100.0	100.0	50.9	100.0	100.0	100.0
3/8"	28.7	91.8	100.0	100.0	28.7	91.8	100.0	100.0
#4	2.8	21.4	98.8	99.3	2.8	21.4	98.8	99.3
#8	2.6	3.0	66.9	88.8	2.6	3.0	66.9	88.8
#16	2.4	2.8	40.8	79.0	2.4	2.8	40.8	79.0
#30	2.2	2.6	27.0	65.3	2.2	2.6	27.0	65.3
#50	2.0	2.4	19.6	13.9	2.0	2.4	19.6	13.9
#100	1.8	1.6	15.7	2.2	1.8	1.6	15.7	2.2
#200	1.8	1.6	13.4	1.5	1.8	1.6	13.4	1.5

"Pan Material"

Example

Coarse Sieves

Fine Sieves

% moist. = (wet wt.		6413.80	- dry wt.) / dry wt. x 100 =			4.7%
ORIGINAL DRY SAMPLE WT. (.01 lbs. / 1g)				6125.90		
sieve size	F.M.	Retained	% total	Acc.% pass.	Acc.% pass.	SPEC
mm in	*	(.01 lb / 1g)	ret. (0.1%)	(0.1%)	(rounded)	REQ.
50.0 2						
37.5 1 1/2						
31.5 1 1/4						
25.0 1				100.0	**100**	100
19.0 3/4		60.10	1.0	99.0	**99**	97-100
16.0 5/8		265.60	4.3	94.7	**95**	
12.5 1/2		400.90	6.5	88.2	**88**	76-90
9.5 3/8	*	605.90	9.9	78.3	**78**	
6.3 1/4		305.80	5.0	73.3	**73**	
4.75 #4	*	583.40	9.5	63.8	**64**	56-66
PAN		3895.60	63.6	**+#4 Gradation check**		
TOTAL		6117.30		92 to 0.3 % of		0.14%
				original dry wt.		
sieve size		Retained	% total	% total x %	Acc.% pass.	Acc.% pass.
mm #		(0.1g)	ret.(0.1%)	pa.#4(0.1%)	(0.1%)	(rounded)
2.36 8	*	124.1	23.5	15.0	48.8	**49**
2.00 10						
1.18 16	*	101.5	19.2	12.2	36.6	**37**
0.850 20						
0.600 30	*					
0.425 40		133.1	25.2	16.1	20.5	**21**
0.300 50	*					
0.180 80		37.1	7.0	4.5	16.0	**16**
0.150 100	*					
0.075 200		57.9	11.0	7.0	9.0	**9**
PAN dry		1.0	14.0	8.9	wt. before washing	(0.1 g)
PAN wash		72.9			wt. after washing	(0.1 g)
TOTAL	*	527.6		loss from washing (- #200)		

Fine sieve gradation is actually based on the amount passing the #4 in the coarse fraction.

The -#4 portion of the JMF gradation will be re-calculated using the % passing the #4 of the stockpile average.

Calculate Aggregate and Binder Batch Weights

- Calculate and prepare laboratory aggregate batches
- Calculate Mb – Binder quantity for each specimen
- Individual specimens recommended

Aggregate Batching

$$Ms = \frac{A \times B \times C}{10{,}000}$$

Ms= the mass of sample needed from a particular sieve fraction
A = stockpile % in the Total Blend
B = the total sample batch weight
C = % retained on the respective sieve fraction

Example

Batch size = 4700 grams

	25%	35%	30%	10%	Composite
Sieve Size	Agg.1	Agg.2	Agg.3	Agg.4	Blend
# 4	2.8	21.4	98.8	85.0	46.3
# 8	2.6	12.2	65.3	78.9	32.4

Calculate the grams of material retained on the # 8 sieve of Agg.3

$Ms =$

Example

Batch size = 4700 grams

	25%	35%	30%	10%	Composite
Sieve Size	Agg.1	Agg.2	Agg.3	Agg.4	Blend
# 4	2.8	21.4	98.8	85.0	46.3
# 8	2.6	12.2	65.3	78.9	32.4

Calculate the grams of material retained on the # 8 sieve of Agg.3

$$Ms = \frac{30 \times 4700 \times (98.8-65.3)}{10{,}000}$$

$$= \frac{4{,}723{,}500}{10{,}000} = 472.4 \text{ grams}$$

Calculating Asphalt Content

- Asphalt binder percentage (Pb) is calculated based on the <u>total weight of the mix.</u>

$$Pb = (Mb / Mm) \times 100$$

Pb = Percent binder based on total weight

Mb = Mass of the Binder in the mix

Mm = Total mass of the mixture

Calculating binder batch weight

$$Mb = \left(\frac{Ms}{1 - \frac{Pb}{100}} \right) - Ms$$

Mb = the mass of asphalt binder needed for a particular batch

Ms = Mass of the aggregate batch weight

Pb = asphalt binder %

Example

Ms = 4700 g *Pb = 4.7%*

Mb =

Example

$Ms = 4700\ g \qquad Pb = 4.7\%$

$$Mb = \left(\frac{4700}{1 - \frac{4.7}{100}} \right) - 4700$$

$$= 4931.8 - 4700.0 = 231.8\ g$$

- **NOTE:** To avoid wasted effort in the laboratory when using unfamiliar materials, the mix designer is encouraged to perform a single point analysis of the volumetric properties prior to performing the complete (multi point or bracketing) analysis. For the purposes of adjusting the trial binder content to the proper void level, the following general rule applies: A 0.2% change in asphalt binder content is approximately a 0.5% change in air voids.

Optional 1-pt. Mix Designs (Selecting a Design Aggregate Structure)

- The design aggregate structure process was developed in the Superpave system and is easily adopted to any volumetric mix design.
- Provides a tremendous amount of volumetric information for multiple aggregate combinations
- Most applicable to new or unfamiliar sources.

Selecting a Design Aggregate Structure

- Select multiple gradation or material combinations that will meet the specifications
  - Complete stockpile data is beneficial
- Prepare and evaluate selected combinations using laboratory data from “mini” 1-pt. mix designs
- May allow for better utilization of existing or alternative materials.

Design Aggregate Structure Process

- Select an initial asphalt binder content for each trial blend
- Conduct Gmb and Gmm testing on each trial blend at 1 asphalt percentage
- Conduct volumetric analysis on each trial blend
- Evaluate trials blends to determine the most appropriate candidate for further mix design analysis

Design Aggregate Structure Specimen requirements

The following samples are necessary for each trial blend:

- 2 laboratory compaction specimens
- 1 or 2 maximum theoretical specific gravity specimens
- Any blended aggregate samples needed to verify aggregate quality criteria (LL, PI or Shale)

Determine the initial binder content ($Pb_{initial}$) for Trial Blends

- Use a reasonable value based on experience or other available information or
- Use AASHTO Provisional Standard, PP-28 Appendix XI

AASHTO Provisional Standard PP-28 Appendix XI

Calculating the Initial Estimated Asphalt Content

	$G_{sb,\ meas}$	$G_{sa,meas}$	$G_{se,initial}$	$V_{ba,initial}$	$V_{be,initial}$	$W_{s,initial}$	$P_{b,initial}$
Blend 1	2.682	2.753	2.739	0.018	0.0897	2.304	4.5%
Blend 2	2.672	2.757	2.740	0.021	0.0897	2.305	4.7%
Blend 3	2.672	2.755	2.738	0.021	0.0897	2.303	4.7%
Blend 4	2.665	2.757	2.739	0.023	0.0897	2.304	4.8%
Blend 5	2.660	2.758	2.738	0.025	0.0897	2.303	4.8%

Assumed

P_b = 5.0% P_s = 95.0% G_b = 1.02 V_a = 4.0%

Gseinit = Gsb + 0.8(Gsa - Gsb)

Vbainit = {[Ps x (1 - Va)] / [(Pb/Gb)+(Ps/Gseinit)]} x {(1/Gsb) - (1/Gseinit)}

Vbeinit = 0.176 - .0675 log(Sn)

Where Sn = the nominal aggregate maximum size in mm. = 19

Wsinit = {Ps x (1-Va)} / {(Pb/Gb)+(Ps/Gseinit)}

Pbinit = {Gb x (Vbeinit+Vbainit)}/{[Gb x (Vbeinit+Vbainit)]+Wsinit}

Conduct laboratory testing on all Trial Blends

Calculate initial volumetric properties for all trial blends

Calculate Initial Volumetric Properties

- Calculate Gmb and Gmm for samples on each trial blend evaluated

$$Gmb = A/(B-C)$$

Where A = Dry Wt.
B = SSD Wt.
C = Submerged Wt.

Calculate Initial Volumetric Properties

(Weighing in Air Method)

Gmm = [A / (A + B – C)] x D

Calculate $Va_{initial}$

$$Va_{initial} = \left(\frac{Gmm_{initial} - Gmb_{initial}}{Gmm_{initial}} \right) \times 100$$

Where,

$Va_{initial}$ = % Air Voids in a trial blend @ $Pb_{initial}$

$Gmm_{initial}$ = Max. Sp. Gr. in a trial blend @ $Pb_{initial}$

$Gmb_{initial}$ = Bulk Sp. Gr. in a trial blend @ $Pb_{initial}$

Example

$Gmb_{initial} = 2.427$ $Gmm_{initial} = 2.634$

Calculate $Va_{initial}$

$Va_{initial} =$

Example

$Gmb_{initial} = 2.427$ $Gmm_{initial} = 2.634$

Calculate $Va_{initial}$

$$Va_{initial} = \left(\frac{2.634 - 2.427}{2.634} \right) \times 100$$

$$= .0786 \times 100 = \mathbf{7.9\ \%}$$

Calculate $VMA_{initial}$

$$VMA_{initial} = 100 - \frac{Gmb_{initial} \times Ps}{Gsb}$$

Where,

$VMA_{initial}$ = % VMA of the trial blend @ $Pb_{initial}$

$Gmb_{initial}$ = Bulk Sp. Gr. of the trial blend @ $Pb_{initial}$

Ps = Percent Aggregate

Gsb = Bulk Sp. Gr. of the Aggregate Blend

Example

$Gmb_{initial}$ = 2.427 $Pb_{initial}$ = 5.5% Gsb = 2.693

Calculate $VMA_{initial}$

$VMA_{initial}$ =

Example

$Gmb_{initial}$ = 2.427 $Pb_{initial}$ = 5.5% Gsb = 2.693

Calculate $VMA_{initial}$

$$VMA_{initial} = 100 - \frac{2.427 \times 94.5}{2.693}$$

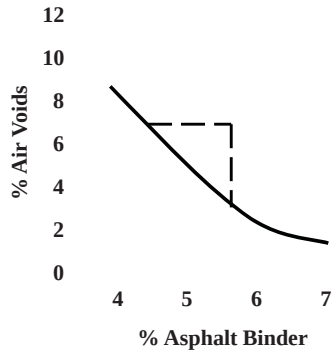
$$= 100 - 85.17 = \mathbf{14.83\%}$$

Adjustments for 4.0% Air Voids

- In all likelihood, the specimens compacted at $Pb_{initial}$ will not contain the design air voids
- By using the real data obtained, we can reasonably determine $Pb_{estimated.}$
- $Pb_{estimated}$ is the binder needed to achieve the design air voids in the trial blends.

$Pb_{estimated}$ Equation

$$Pb_{estimated} = Pb_{initial} - \left[0.4 \times \left(Va_{design} - Va_{initial}\right)\right]$$



Slope of Va curve

0.4% Binder = 1% A.V.

Va_{design} = **4.0**

$Pb_{estimated}$ Example

$Pb_{initial}$ = 5.6% $Va_{initial}$ = 1.6%

Calculate $Pb_{estimated}$ *for a Class 33 Mix*

$Pb_{estimated}$ =

$Pb_{estimated}$ Example

$Pb_{initial}$ = 5.6% $Va_{initial}$ = 1.6%
Calculate $Pb_{estimated}$ *for Mix*

$$Pb_{estimated} = 5.6 - [0.4 \times (4 - 1.6)]$$

$$= \mathbf{4.6\ \%}$$

Calculate $VMA_{estimated}$

$$VMA_{estimated} = VMA_{initial} + [C \times (Va_{design} - Va_{initial})]$$

C = Constant = 0.1 if Va is less than 4.0%
= 0.2 if Va is greater than 4.0%

Experience with materials in your region will allow you to "fine tune" C.

$VMA_{estimated}$ Example

$Va_{initial}$ = 1.6% $VMA_{initial}$ = 13.4%

Calculate $VMA_{estimated}$ *for an HVT Design*

$$VMA_{estimated} =$$

$VMA_{estimated}$ Example

$Va_{initial}$ = 1.6% $VMA_{initial}$ = 13.4%

Calculate $VMA_{estimated}$ *for an HVT Design*

$$VMA_{estimated} = 13.4 + \left[0.1 \times \left(4 - 1.6 \right) \right]$$

$$= \mathbf{13.6\ \%}$$

Calculate $VFA_{estimated}$

$$VFA_{estimated} = 100 \times \left[\frac{\left(VMA_{estimated} - Va \right)}{VMA_{estimated}} \right]$$

Va = 4.0 for Target

$VFA_{estimated}$ Example

$VMA_{estimated}$ = 13.6% HVT Mix

$VFA_{estimated}$ =

$VFA_{estimated}$ Example

$VMA_{estimated}$ = 13.6% HVT Mix

$$VFA_{estimated} = 100 \times \left[\frac{(13.6 - 4.0)}{13.6} \right]$$

$$= 70.6\ \%$$

Calculate Gse

$$Gse = \frac{Pmm - Pb}{\frac{Pmm}{Gmm} - \frac{Pb}{Gb}}$$

where,

Gse = Effective specific gravity of the aggregate
Pmm = 100
Pb = Percent asphalt binder
Gmm = Theoretical maximum specific gravity of the mixture
Gb = Specific gravity of the asphalt binder

Example

$Pb_{initial}$ = 5.6% Gb = 1.02 $Gmm_{initial}$ = 2.469
Calculate *Gse*

$$Gse =$$

Example

$Pb_{initial}$ = 5.6% Gb = 1.02 $Gmm_{initial}$ = 2.469
Calculate *Gse*

$$Gse = \frac{100 - 5.6}{\frac{100}{2.469} - \frac{5.6}{1.02}}$$

$$= \frac{94.4}{40.50 - 5.49} = \mathbf{2.696}$$

Calculate $Pbe_{estimated}$

$$Pbe_{estimated} = Pb_{estimated} - \left[(Ps \times Gb) \times \left(\frac{Gse - Gsb}{Gse \times Gsb} \right) \right]$$

$Pbe_{estimated}$ = the estimated effective binder content had the trial blend used $Pb_{estimated}$

Ps = aggregate content, percent by total mass of the mixture

Gb = specific gravity of the asphalt

Gse = effective specific gravity of the aggregate

Gsb = bulk specific gravity of the aggregate

$Pb_{estimated}$ = the asphalt content needed to obtain a mixture at 4.0% air voids

$Pbe_{estimated}$ Example

Ps = 95.7 Gb = 1.02 Gse = 2.754

Gsb = 2.699 Pb = 4.3 Calc $VFA_{estimated}$

$Pbe_{estimated}$ =

$Pbe_{estimated}$ Example

Ps = 95.7 Gb = 1.02 Gse = 2.754

Gsb = 2.699 Pb = 4.3 Calc $VFA_{estimated}$

$$Pbe_{estimated} = 4.3 - (95.7 \times 1.02) \times \left(\frac{2.754 - 2.699}{2.754 \times 2.699} \right)$$

$$= 3.6\ \%$$

$DP_{estimated}$

$Pbe_{estimated}$ = 3.6 $P_{0.075}$ = 3.1

$$DP = \frac{P_{0.075}}{Pbe_{estimated}} =$$

$DP_{estimated}$

$Pbe_{estimated} = 3.6$ $P_{0.075} = 3.1$

$$DP = \frac{P_{0.075}}{Pbe_{estimated}} = \frac{3.1}{3.6} = \mathbf{0.86}$$

Analysis of Trial Blends

Estimated Properties @ 4.0% Air Voids						
	Specimen	$P_{b,est}$	VMA_{est}	VFA_{est}	$P_{be,\ est}$	DP_{est}
	Trial Blend 1	4.12	11.51	65.3	3.1	1.7
	Trial Blend 2	3.65	12.10	66.9	2.8	1.0
	Trial Blend 3	4.77	13.09	69.4	3.7	1.7
	Trial Blend 4	5.04	12.53	68.1	3.8	2.1
	Trial Blend 5	4.00	11.33	64.7	3.0	2.0

Conduct a full mix design on optimum blend

Student Problem

TRIAL MIXTURE ANALYSIS

Given: **You have been assigned the responsibility of reviewing the following mix design for a Superpave FAA 45 mixture for an upcoming project.** The fractured face, fine aggregate angularity and other aggregate quality parameters have been determined.

The combined blend aggregate information is as follows:

Gradation	% Passing
5/8"	100
½"	97
3/8"	85
No. 4	64
No. 8	52
No. 16	43
No. 30	33
No. 50	18
No. 100	8
No. 200	5.7

Aggregate Specific Gravity, (Composite Blend)
Gsb = 2.600
Gsa = 2.747
Water absorption, % by dry weight of aggregate = 2.1%

Solution: **You have decided to make a trial mixture for initial analysis, to determine how suitable this mixture would be.** The given gradation is combined into a batch at 6 percent asphalt, and the following results were determined:

Mixture properties at 6 percent asphalt:

Gmm	=	2.461
Gmb	=	2.367
Gb	=	1.028

Student Problem (Con't)

Questions:

•What would the estimated asphalt content of this gradation be at 4 percent air voids?

•What is the estimated asphalt absorption?

•What is the estimated fines-to-asphalt ratio?

•What is the mixture's VMA?

•What are your insight(s) on the proposed mixture regarding air voids, VMA and fines to asphalt ratio?

•How suitable is this mixture for a Superpave mixture?

Dakota Asphalt Pavement Association Inc.

ND QC/QA Asphalt Concrete Mix Controller

Volumetric Design & Analysis

Laboratory Mixture Testing

- Determine the laboratory mixing and compaction temperatures
- Conduct laboratory testing
  - 3 Gmb specimens @ 5 different Pb @ 0.5% increments
  - 2 Gmm specimens @ the next to last Pb.
  - 2 hour cure time for both Gmb and Gmm specimens
- Conduct volumetric analysis

Laboratory Mixing and Compaction Temperatures

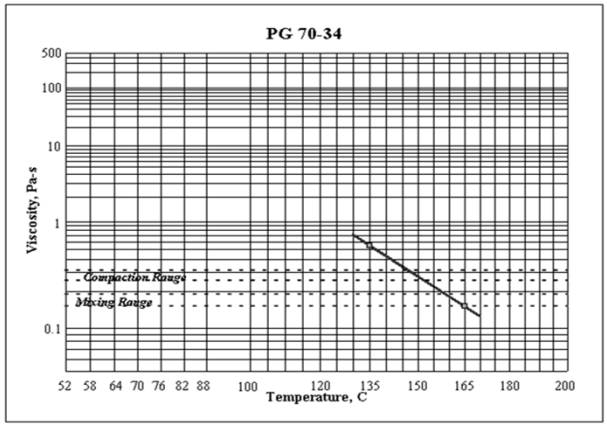
- The use of temperature viscosity curves are to establish a uniform mix design procedure
- Traditional (AASHTO T-245) temperature specifications are
  - Laboratory Mixing = 170 ± 20 centistokes
  - Laboratory Compaction = 280 ± 30 centistokes
- Not intended for field production
  - Mixing Temperature may be a starting point
- Verify mixing/compaction temperatures fall within the AASHTO values

Temperature Viscosity Worksheet

Binder: PG 70-34

Temp (C)	Viscosity (cp)
135	550
165	150

Mixing Temperature Range, C	159 - 165
Compaction Temperature Range, C	147 - 152
Mixing Temperature Range, F	318 - 329
Compaction Temperature Range, F	297 - 306



Laboratory Mixture Testing

- The laboratory mixture testing determines primarily two values
  - Gmb – Bulk specific gravity of the mix
  - Gmm – Theoretical maximum specific gravity

Gmb – Bulk Gravity of the Mix

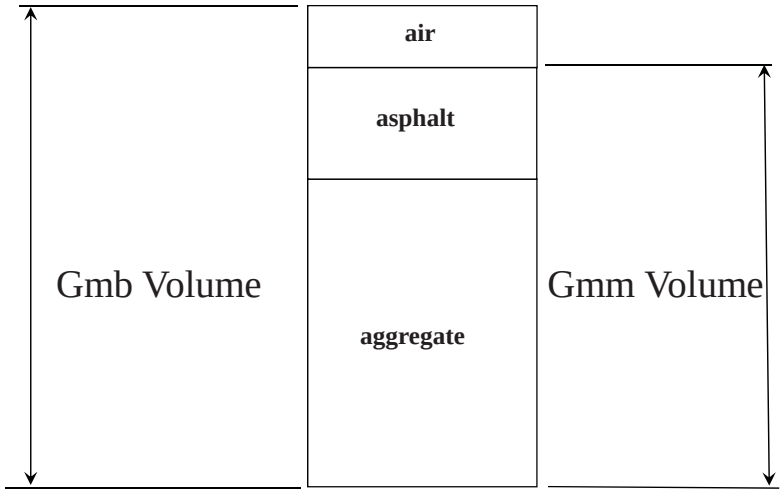
- The Gmb is the density *(in g/cm^3)* of the laboratory compacted specimen, including the air voids.
- Also called the "design density", Gmb should represent the ultimate density that will be achieved on the road from future traffic.

Gmm – Theo. Max. Gravity

- Also called the Rice Density or Voidless Density
- Gmm is the density of the individual asphalt coated particles. Air Voids are not involved.
- Gmm is heavier than Gmb due to a smaller volume

$$G = M/V$$

Gmb Vs Gmm



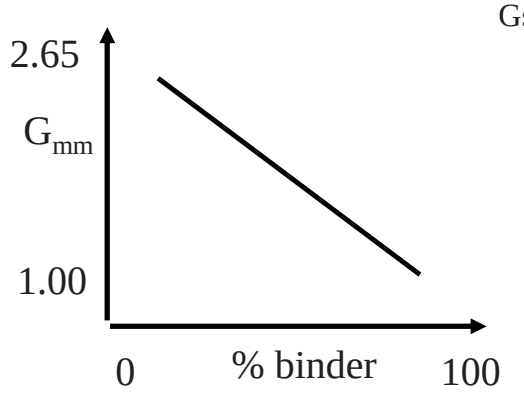
Gmb vs. Gmm Relationships

Gmb Variables	Gmm Variables
▪ Mix Temperature	▪ Vacuum
▪ Compaction	▪ Representative sample
▪ Marsh – blow count	▪ Sample preparation
▪ Marsh – rodding	▪ Better repeatability
▪ Aggregate alignment	

Gmm Characteristics

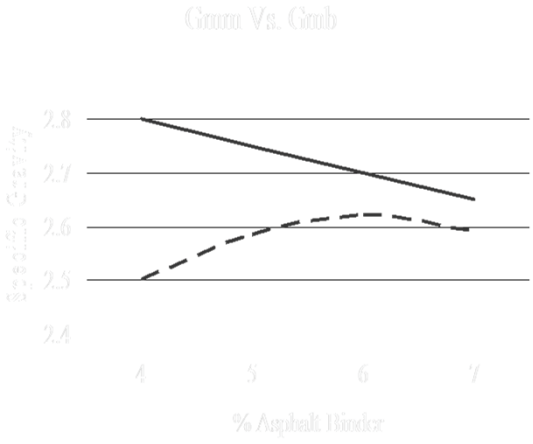
Gb ~ 1.02

Gs ~ 2.65



Pros and Cons of Gmm

- Representative sampling is critical
- Excellent parameter for field monitoring
- Can lead to over asphalted mixtures in the field



Calculate Gmb for each Specimen

Gmb = A/(B-C)

Where A = Dry Wt.
B = SSD Wt.
C = Submerged Wt.

Calculate Gmm for the specimens tested at one Pb

$$Gmm = [A / (A + B - C)] \times D$$

Calculate Gmm for the specimens tested at one Pb

(Weighing in Water Method)

$$Gmm = [A / (A + B - C)] \times D$$

Where
A = Weight of Sample in Air
B = Weight of Container under Water
C = Wt. Container+Sample under Water
D = Water Correction Factor

Back calculate Gmm for other Pb

- ND assumes a constant asphalt absorption rate for mix design purposes
- Conventionally the Gmm specimen should be run at the same Pb as the next to last Gmb specimen
- We must first calculate Gse so we can calculate Gmm at all the other Pb.

Gse – Effective Specific Gravity

$$G_{se} = \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}}$$

Gse = Effective Specific Gravity of the aggregate

Pb = Percent asphalt binder

Gmm = Theoretical maximum specific gravity of the mix

Gb = Specific Gravity of the asphalt binder

Gse Example

Pb = 5.0% Gb = 1.02 Gmm = 2.524
Calculate Gse

G_{se} =

Gse Example

Pb = 5.0% Gb = 1.02 Gmm = 2.524
Calculate Gse

$$G_{se} = \frac{100 - 5.0}{\frac{100}{2.524} - \frac{5.0}{1.02}} = \frac{95}{39.62 - 4.90}$$

$$= 2.736$$

Back calculate Gmm at other Pb

$$Gmm = \frac{Pmm}{\frac{Ps}{Gse} + \frac{Pb}{Gb}}$$

Gmm = Theo. Max. Sp. Gr. Back calculated from original measured Gmm

Pmm = 100

Ps = Percent aggregate in the specimen

Gse = Effective specific gravity of the aggregate

Pb = Percent asphalt binder

Gb = Specific gravity of the asphalt binder

Back calculate Gmm at other Pb

If Gb = 1.02 Gse = 2.736

Calculate Gmm@ 3.5, 4.0, 4.5 & 5.5%

$Gmm_{@3.5\%} =$

Back calculate Gmm at other Pb

If Gb = 1.02 Gse = 2.736

Calculate Gmm@ 3.5, 4.0, 4.5 & 5.5%

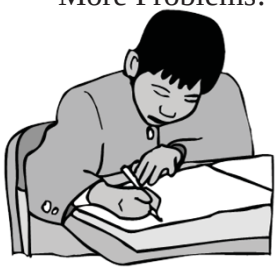
$$Gmm_{@3.5\%} = \frac{100}{\frac{96.5}{2.736} + \frac{3.5}{1.02}}$$

$$= \frac{100}{35.27 + 3.43} = \mathbf{2.584}$$

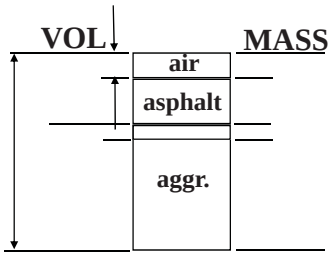
Calculate Remaining Volumetric Properties

- Va
- VMA
- VFA
- Pbe
- DP

More Problems!



Air Voids



- Definition
  - volume concentration of air voids
- % by volume total mix, V_a

Va Equation

$$Va = \left(\frac{Gmm - Gmb}{Gmm} \right) \times 100$$

Va = % Air Voids in the mixture

Gmb = bulk specific gravity of the mixture

Gmm = theoretical maximum specific gravity of the mixture

Va Example

Gmb = 2.375 Gmm = 2.523

Calculate Va

$$Va =$$

Va Example

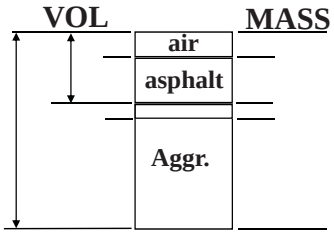
Gmb = 2.375 Gmm = 2.523

Calculate Va

$$Va = \left(\frac{2.523 - 2.375}{2.523} \right) \times 100$$

$$= \mathbf{5.87\ \%}$$

VMA = Voids in Mineral Aggregate



- Definition
  - volume concentration of *intergranular* void space in a compacted mix
- % by volume total mix
- *Does not* include volume of absorbed asphalt (use G_{sb} *not* G_{se})

VMA Equation

$$VMA = 100 - \frac{Gmb \times Ps}{Gsb}$$

VMA = Voids in the Mineral Aggregate
Gmb = bulk specific gravity of the mix
Ps = Percent aggregate in the specimen
Gsb = bulk specific gravity of the aggregate blend

VMA Example

Pb = 5.5% Gmb = 2.435 Gsb = 2.618

Calculate VMA

$$VMA =$$

VMA Example

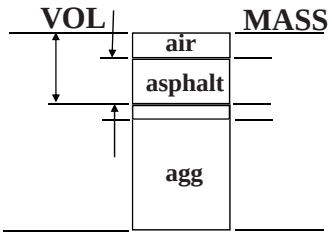
Pb = 5.5% Gmb = 2.435 Gsb = 2.618

Calculate VMA

$$VMA = 100 - \frac{2.435 \times 94.5}{2.618}$$

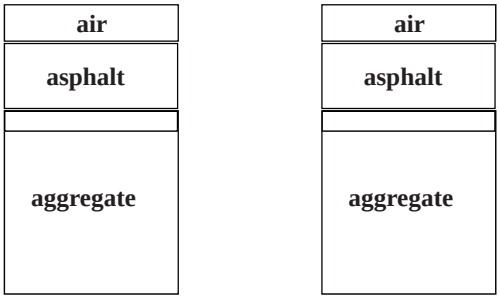
$$= \mathbf{12.11\ \%}$$

Voids Filled with Asphalt (VFA)



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

Limiting excessive VMA



VFA Equation

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

VFA = Percent volume of VMA filled with asphalt
VMA = Percent Voids in the Mineral Aggregate
Va = Percent Air Voids of the Total mix volume

VFA Example

- VMA = 12.11% Va = 4.0%
- Calculate VFA

$$VFA =$$

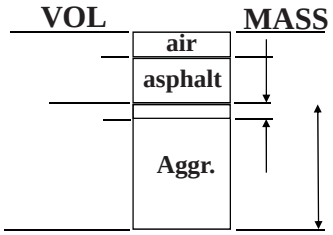
VFA Example

- VMA = 12.11% Va = 4.0%
- Calculate VFA

$$VFA = 100 \times \frac{(12.11 - 4.0)}{12.11}$$

$$= \mathbf{67.0\ \%}$$

Absorbed Asphalt Content



- Definition
  - mass concentration of asphalt absorbed by aggregate
- % by mass of aggregate, P_{ba}

Pba Equation

$$Pba = 100 \times \left(\frac{Gse - Gsb}{Gse \times Gsb} \right) \times Gb$$

Pba = Percent absorbed asphalt
Gse = Effective specific gravity of the aggregate
Gsb = Bulk specific gravity of the aggregate
Gb = Specific gravity of the asphalt binder

Pba Example

Gse = 2.736 Gsb = 2.618 Gb = 1.02
Calculate Pba

$Pba =$

Pba Example

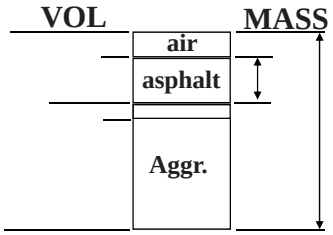
Gse = 2.736 Gsb = 2.618 Gb = 1.02

Calculate Pba

$$Pba = 100 \times \left(\frac{2.736 - 2.618}{2.736 \times 2.618} \right) \times 1.02$$

$$= \mathbf{1.68\ \%}$$

Effective Asphalt Content



- Definition
  - mass concentration of asphalt not lost to absorption
- % by mass of total mix, P_{be}

Pbe Equation

$$Pbe = Pb - \left(\frac{Pba}{100} \times Ps \right)$$

Pbe = Percent effective asphalt binder
Pb = Percent asphalt binder
Pba = Percent absorbed asphalt binder
Ps = Percent aggregate

Pbe Example

Pb = 5.9% Pba = 1.68%
Calculate Pbe

$$Pbe =$$

Pbe Example

Pb = 5.9% Pba = 1.68%

Calculate Pbe

$$Pbe = 5.9 - \left(\frac{1.68}{100} \times 94.1 \right)$$

$$= \mathbf{4.32\ \%}$$

Dust Proportion

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

Dust Proportion

- The “mastic” (asphalt and dust) affects the properties of the mix
  - Excessive dust dries out the mix reducing film thickness and durability properties
  - Insufficient dust may allow excessive asphalt films which may result in tender, unstable mixes

Dust Proportion

- Originally established using the total asphalt content
- Pbe is now recommended
- Usage of Pb or Pbe varies in different regions – Check the specifications.
- Specification Criteria
  - 0.6 – 1.4 Q-MVT
  - 0.6 – 1.2 Q-HVT

D.P. Example

% Passing .075 mm sieve = 5.8% Pbe = 4.3%

Calculate D.P.

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

D.P. Example

% Passing .075 mm sieve = 5.8% Pbe = 4.3%

Calculate D.P.

$$DP = \frac{P_{0.075}}{Pbe} = \frac{5.8}{4.3} = \mathbf{1.3\ \%}$$

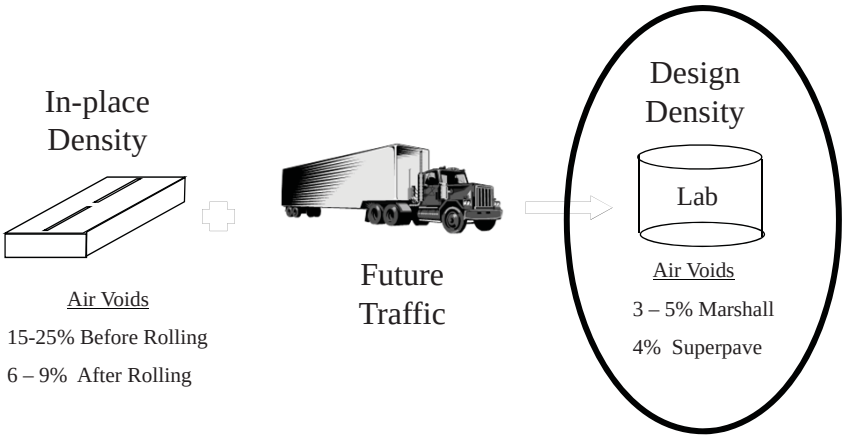
Gyratory Compaction

Superpave Gyratory Compactor

- The SGC is a result of SHRP Research
- Allows for constant monitoring of specimen height during the compaction process
- Superpave specifies 3 different levels of compaction when utilizing an SGC
    - Ndes
    - Nini
    - Nmax

SGC – Ndes *(design)*

- The number of design gyrations as determined by ESAL loading. Ndes = 50,65,75 or 85 gyrations See Spec. Prov. for Gyratory Controlled Mix



Nini and Nmax

- The ability of the SGC to monitor specimen height allows us to build compaction curves
- These curves reflect the stiffness or workability of a mixture
- Initial and Maximum compaction criteria are expressed in terms of %Gmm

Nini *(initial)*

- Specified maximum %Gmm at a low number of gyrations Nini=6 or 7
- %Gmm@Nini = < 91.5, 91.0, 90.5, 90.0, or 89.0% depending on traffic level (check Plan Notes)
- Rapid consolidation at a low number of gyrations is an indication of tender or unstable mixtures.
- This parameter is a performance indicator of the aggregate and binder properties

Nmax *(maximum)*

- Specified maximum %Gmm at a high number of gyrations Nmax = 100, 115, or 130 (Check Plan Notes)
- %Gmm@Nmax = < 98.0% for all Q levels
- This parameter is in essence a safety factor for poor current or future traffic forecasting
- This parameter is a performance indicator of the aggregate and binder properties

Calculating %Gmm @ Nini, Ndes or Nmax

$$\%Gmm_x = 100(Gmb_x / Gmm)$$

Gmm is the same regardless of N

Therefore: Gmb must be determined at Nini, Ndes and Nmax

Calculating %Gmm @ Nini, Ndes or Nmax

- Since we are dealing with a fixed mold size and the SGC accurately measures the height, we can mathematically <u>estimate</u> Gmb

Remember, $G = M / V$

- This is an <u>estimated</u> Gmb because specimen surface irregularities are included in the mathematical calculation of the volume.

Calculating %Gmm @ Nini

Correcting for the surface irregularities

Correction Factor =

$C = h@N_{des} / h@N_{ini}$

- h = height of specimen
- N*des* is the number of gyrations at which the Gmb sample is actually weighed up and measured.
- N*ini* is the number of gyrations at which we do not have a measured Gmb sample.

Calculating %Gmm @ Nini, Ndes or Nmax

Calculating corrected Gmb

$Gmb@N_{ini} = C \times Gmb@N_{des}$

To Calculate %Gmm@N*ini*

$\%Gmm@N_{ini} = (Gmb@N_{ini} / Gmm) \times 100$

% Gmm Example

$$Vol.cylinder = \left(\frac{\pi D^2}{4}\right) \times h$$

N	Ht. mm	C	Gmb_{Corr}	%Gmm
Nini = 8	127.3			
Ndes=109	115.8			

<u>Known Data</u>	Mm = 4887.5 g	Gmb@Ndes = 2.483
Pb = 4.9%	Mb = 239.5 g	150 mm mold
Gsb = 2.689	Gsa = 2.779	Gse = 2.742
Gb = 1.019	Gb = 1.019	Gmm = 2.568

% Gmm Answer

N	Ht. mm	C	Gmb_{Corr}	%Gmm
Nini = 8	127.3			
Ndes=109	115.8			

% Gmm Answer

N	Ht. mm	C	Gmb_{Corr}	%Gmm
Nini = 8	127.3	115.8 / 127.3 **=.9097**	.9097 x 2.483 = **2.2588**	2.2588 / 2.568 = **88.0%**
Ndes=109	115.8	115.8 / 115.8 **= 1.000**	1.000 x 2.483 = **2.483**	2.483 / 2.568 = **96.7%**

Needed Data: Gmb@Ndes = 2.483 Gmm = 2.568

Questions?

ND QC/QA Asphalt Concrete
Mix Controller
Design Binder Content Selection

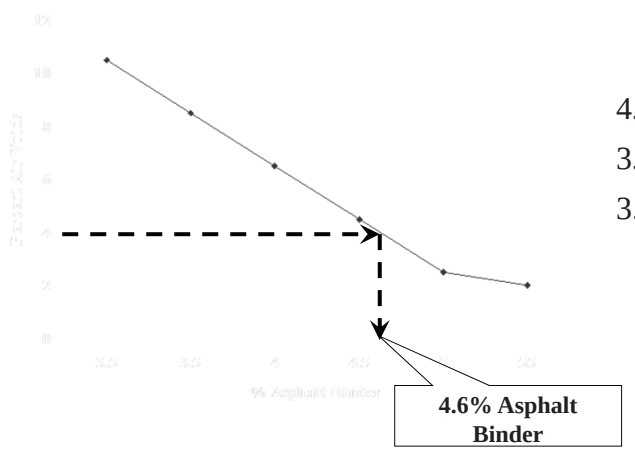
HMA
Mixture Design

- Conduct volumetric mix design on selected trial blend
- Conduct stability and flow analysis
- Evaluate mixture for moisture sensitivity

Select Design Asphalt Content

- Select the asphalt content that corresponds to 4.0 % Air Voids
- Verify that remaining mixture properties meet the mixture criteria
  - **VMA**
  - **VFA**
  - **Dust Proportion**
  - **N_{ini}**

Determine Asphalt Content at Specified Design Air Void Content

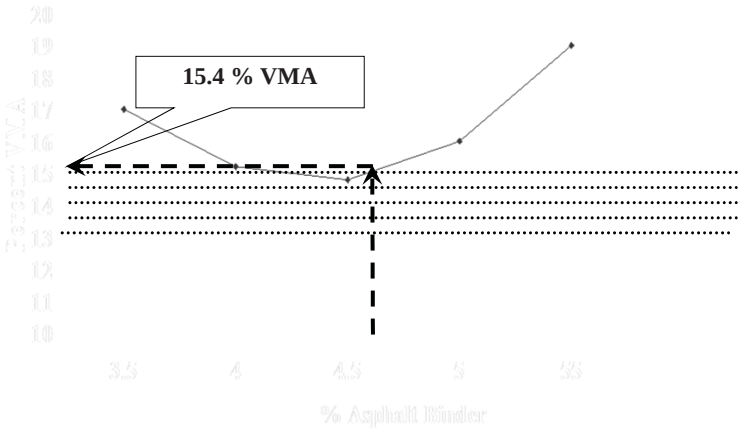


4.0 HVT

3.5 MVT

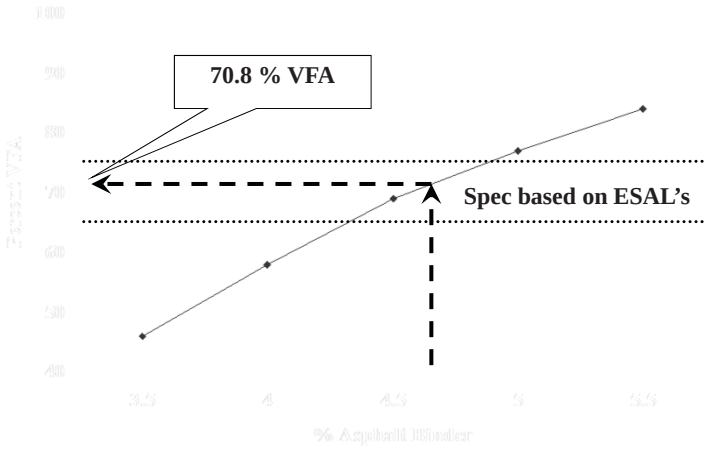
3.0 LVT

Verify VMA

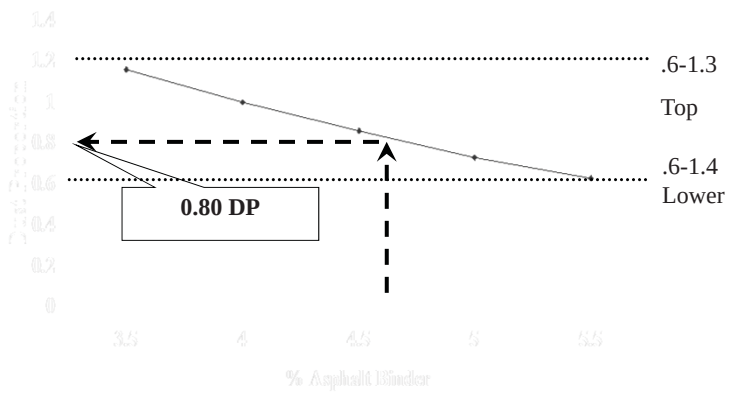


1/2” (12.5 mm) nominal maximum size 14.0 Min.

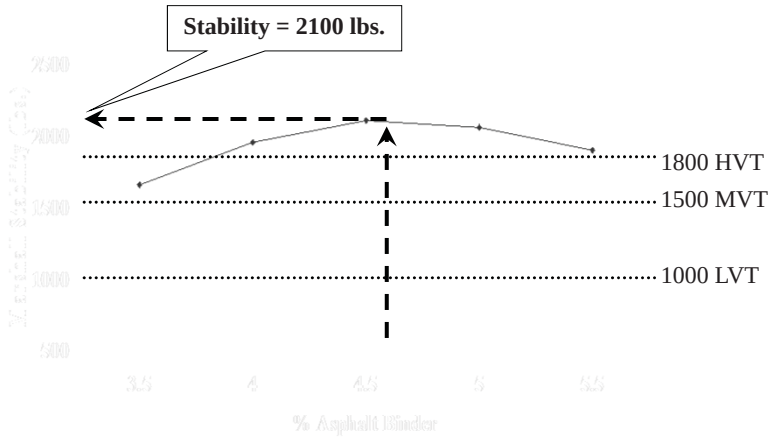
Verify VFA (Recommended)



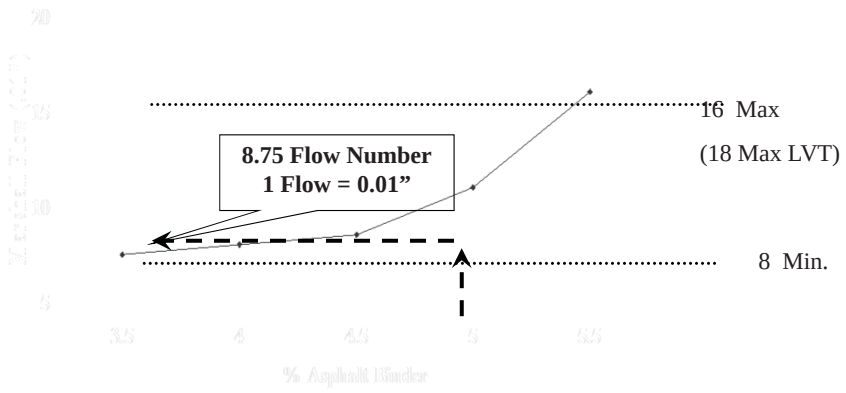
Dust / Binder Ratio



Marshall Stability

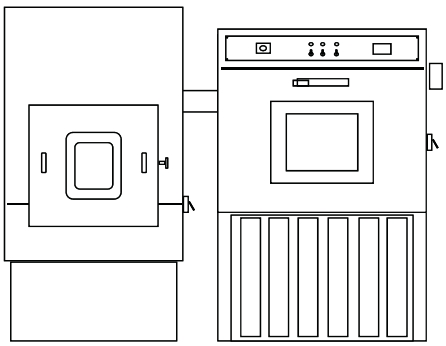


Marshall Flow



Phase 2 - Performance Testing

- Marshall Stability
- SST
- APA
- Hamburg
- Ga. Loaded Wheel
- ALF
- Moisture Sensitivity



Nmax Verification

Nini Verification

ND QC/QA Asphalt Concrete
Mix Controller
Mix Design Submittal to DOT

Contractor Furnished Mix Designs:

Asphalt concrete mix designs shall be performed by the Contractor and verified by the Department when so designated on the Plans.

Two Types of Mix Designs:

- Department-Developed Mix Design
- Contractor Developed Mix Design

Two Types of Submittals:

- Preliminary Mix Design (10000 tons of Aggr.)
- Project JMF: After a min. of 10000 tons of Aggr.

Two Types of JMF's:

- Trial Mix Design/Aggregate Blend Determination
- Final Mix Design/JMF Determination

Contractor Furnished Mix Designs Con't:

When RAP is required the Contractor shall sample the RAP materials from the roadway by an approved method. This material shall be used to perform the mix design. A portion of the sample shall be submitted to the Department's Bituminous Mix Design Lab. The Contractor shall notify the Area Engineer prior to sampling material from the roadway.

Samples for aggregate quality testing shall be submitted to the Department..a minimum of fifteen working days prior to hot mix production. Mix designs will only be performed on samples when accompanied by the following information:

Verification Design Submittal Recommendations

a. An aggregate sample representing each stockpile (combined sample of at least 150 lbs.)
b. Eight (8) one-quart cans of PG asphalt of type and grade specified and supplier
c. Approximately 30 lbs. of loose asphaltic concrete mixture

Verification Design Submittal Requirements

d. Job Mix Formula (JMF) with the following
- Gradation of Combined (Average) Aggregate Material
- Asphalt Content
- Specified Target Air Void Content = 4.0%
- G_{mm} of mixture obtained in Laboratory
- G_{mb} of mixture obtained in Laboratory
- VMA of mixture obtained in Laboratory
- Calculated Film Thickness
- Calculated dust/asphalt ratio or dust proportion
- $\%G_{mm}$ at N_{ini}
- $\%G_{mm}$ at N_{max}
- Submitted with the NDDOT Mix Design Program or approved equal minimum of 10-days prior to operations
- Criteria in Standard Specifications: Table 430-05

Verification Design Submittal Requirements

Job Mix Formula (JMF) must be resubmitted if:
- Utilizing aggregates from sources not initially submitted
- Aggregates processed from same source utilizing a different crusher
- Utilize a different type or grade of asphalt cement
- Change in source of asphalt cement*

* Immediately notify the Engineer with relevant information on source. Engineer may request a new mix design.

Questions?

ND QC/QA Asphalt Concrete Mix Controller

RAP Mix Design

What is RAP ?

Reclaimed **A**sphalt **P**avement

Old asphalt pavement that has been removed from the roadway by either milling or full-depth removal.

Extraction and Recovery Procedures

- Extraction
  - Determine asphalt content of RAP
  - Determine RAP aggregate gradation
  - Necessary for mix design
- Recovery
  - Determine asphalt binder physical properties
  - Necessary for blending charts
    - Usually for high % of RAP (greater than 20-25%)

Binder Grade Selection for RAP Mixtures

ACTION	RAP
No Change in Binder Grade	15% or less
One Grade Lower	16 - 25%
Use Blending Charts	>25%

Asphalt Mix Design Using RAP

- When using RAP in asphalt mix designs, the aggregate gradations and the total binder content are altered slightly from the original batch percentages due to the binder contained in the RAP.

Asphalt Mix Design Using RAP

- When RAP is allowed, it will not be included in meeting the total aggregate requirements set forth in plans, Specials or Specifications.
- When RAP is included, determine the asphalt binder content by conducting two extractions or ignition oven tests (w/ CF).

Asphalt Mix Design Using RAP

- The gradation for the RAP shall be determined from two extractions or ignition oven tests and the results shown (avg.) on the mix design sheet.
- When 20% or less of RAP is added the the Gsb from the virgin mineral aggregate for the Gsb of the mixture…..

Asphalt Mix Design Using RAP

- The first step is to determine the binder content and gradation of the RAP aggregate.
- The next step is to determine the RAP percentage that will be used in the trial mix blend. RAP is considered another aggregate material.
- Since RAP contains a certain amount of binder, the actual weight of the aggregate in the mixture blend will be less than normal.

Asphalt Mix Design Using RAP

- Taking the binder in the RAP into account, the actual aggregate blend percentages need to be adjusted and the gradation of the blend determined.
- An alternative procedure would be to determine the weight of RAP needed to result in a desired weight of aggregate. We will look at both procedures.

Asphalt Mix Design Using RAP

- The weight of the required binder to be added to the mixture must be determined to achieve a desired total binder content by weight of mixture.
- The total binder content is a combination of the “old” and “new” binder in the mix
- The virgin aggregate, RAP and new asphalt binder are mixed together and tested much the same way as a mixture containing all virgin aggregates and new binder

Asphalt Mix Design Using RAP Example

After performing extraction/gradation testing, the results of the RAP aggregate gradation and asphalt content are as follows:

RAP Properties

Sieve Size	Percent Passing
1”	100
¾”	90
½”	75
#4	60
#8	50
#16	40
#40	35
#80	11
#200	8.0

Asphalt content of the RAP = 3.5%

Asphalt Mix Design Using RAP

- A blend of two virgin aggregates and the RAP shown are to be used for a trial mix. The RAP will be used in the mix at 25% of the total aggregate weight. Aggregate #2 will be added at 50% and Aggregate #3 at 25%.

Asphalt Mix Design Using RAP

- For a total cold feed batch weight of 1100 grams, including the RAP, determine the weight of each material to add to the aggregate blend

RAP weight = 1100 (0.25) = 275 grams

Aggregate #2 = 1100 (0.50) = 550 grams

Aggregate #3 = 1100 (0.25) = 275 grams

1100 grams

Asphalt Mix Design Using RAP

- Since the RAP contains 3.5% binder, the actual aggregate and asphalt binder weight in the RAP need to be determined

Wt. of old binder = 275 (0.035) = 9.6 grams

Wt. of aggr. = 275 (0.965) = 265.4 grams

Asphalt Mix Design Using RAP

- The total aggregate weight in the blend is then determined

Total aggr. wt.= 265.4 + 550 + 275
= 1090.4 grams

Asphalt Mix Design Using RAP

- The actual aggregate blend percentages need to be adjusted based on the calculated total aggregate weight

Percent RAP aggr. = 265.4/1090.4 = 24.3 %

Percent of Aggr. #2 = 550/1090.4 = 50.4%

Percent of Aggr. #3 = 275/1090.4 = 25.3%

100.0 %

Asphalt Mix Design Using RAP

- The combined aggregate blend for the three aggregates used in this mix would then be calculated using the above percentages of each aggregate
- The next step is to determine the amount of new asphalt binder to add to the RAP and virgin aggregate blend to achieve the desired total binder content of the mixture

Asphalt Mix Design Using RAP Example

- Determine the weight of new binder to add to the mix for a total binder content of 6.0% by weight of mix.

$$\text{Wt. of binder} = \frac{\text{wt. Aggr. X 100}}{100 - \%\ \text{binder}} - \text{wt. Aggr.}$$

$$\text{Wt. of binder} = \frac{(1090.4)\ \text{X 100}}{100 - 6.0} - 1090.4$$

Total Wt. of binder = 69.6 grams

Asphalt Mix Design Using RAP

- 69.6 grams is the total binder weight needed to achieve a total binder content of 6.0% with our pre-determined aggregate weight of 1090.4 grams. We also know that there are 9.6 grams of old binder in the RAP. Therefore, we need to determine the weight of the “new” binder to add to get 6.0%.

Asphalt Mix Design Using RAP

- Weight of new binder = (wt. of total binder – wt. of old binder)

Wt. new binder = (69.6 – 9.6) = 60.0 grams

Wt. of aggr. = 1090.4 grams

Wt. of new binder = 60.0 grams

Wt. of old binder = 9.6 grams

Total mix weight = 1160.0 grams

Total binder content = (69.6/1160.0)100 = 6.0%

Summary – 1100 g Cold Feed Batch

	Batch Wts.	Cold Feed %	Grad. %
RAP	265.4 (Agg)	25 %	24.3 %
Agg. 2	550	50 %	50.4 %
Agg. 3	275	25 %	25.3 %
RAP Binder	9.6		
New Binder	60.0		

% Total Binder = 6.0 %

% New Binder = 60 / 1160.0 = 5.17 %

Asphalt Mix Design Using RAP

- An alternate procedure is to assume that a total aggregate weight of 1100 grams is desired. This weight includes the virgin aggregate and the RAP aggregate only. This does not include the weight of old asphalt in the RAP.

Asphalt Mix Design Using RAP

- Determine the weight of RAP needed to result in 275 grams of RAP aggregate being added to the mixture.

$$\text{Wt. Of RAP} = \frac{\text{(wt. RAP Aggr.)}}{\text{(100 - \% RAP Binder)}} \times 100$$

$$\text{Wt. Of RAP} = \frac{275}{(100 - 3.5)} \times 100$$

Wt. Of RAP = 285.0 grams

Wt. Old binder = 285.0 – 275.0 = 10.0 grams

Asphalt Mix Design Using RAP

- Determine the weight of binder to add to the mix to achieve a total binder content of 6.0% by weight of mix

$$\textbf{Wt. of binder} = \frac{\textbf{wt. Aggr. X 100}}{\textbf{100 - \% binder}} - \textbf{wt. Aggr.}$$

$$\textbf{Wt. of binder} = \frac{\textbf{(1100 X 100)}}{\textbf{100 – 6.0}} - \textbf{1100.0}$$

Wt. of total binder = 70.2 grams

Asphalt Mix Design Using RAP

- The total binder weight is 70.2 grams. We know that we have 10.0 grams in the RAP added to the mixture. Therefore, we need to determine the weight of new binder to add to get to the total desired.

Wt. Of new binder = (70.2 - 10.0) = 60.2 grams

Asphalt Mix Design Using RAP

- For a pre-determined aggregate weight of 1100.0 grams, including the RAP aggregate and the virgin aggregate, the total mix weight can be determined.

Wt. RAP aggr. = 275.0 grams

Wt. Aggr. #2 = 550.0 grams

Wt. Of Aggr. #3 = 275.0 grams

Total aggr. Wt. = 1100.0 grams

Asphalt Mix Design Using RAP

Wt. Aggregate = 1100.0 grams

Wt. Old binder = 10.0 grams

Wt. New binder = 60.2 grams

Total mix wt. = 1170.2 grams

Total binder content = (70.2/1170.2)100 = 6.0%

With this information, we can also calculate the % of new binder added to the mix (by wt. of mix)

% added binder = (60.2/1170.2) 100 = 5.1%

Asphalt Mix Design Using RAP Example Problem

- You are asked to do a trial mix using the following materials:
  - 35% RAP
  - 15% Coarse Aggregate
  - 46% Fine Aggregate
  - 4% Mineral Filler
- If the RAP has a binder content of 4.7%, what are the adjusted aggregate blend percentages? (Use a batch weight of 3000.0 grams including RAP and virgin aggregate)

Asphalt Mix Design Using RAP Example Problem

- Using the previous information, what weight of new asphalt must be added to achieve a total binder content of 4.5% by weight of mix?
- What is the percent added binder by weight of mixture?

Asphalt Mix Design Using RAP Example Problem

- You are asked to do a trial mix using the following materials:
  - 35% RAP
  - 15% Coarse Aggregate
  - 46% Fine Aggregate
  - 4% Mineral Filler
- If the RAP has a binder content of 4.7%, what are the adjusted aggregate blend percentages? (Use a batch weight of 3000.0 grams including RAP and virgin aggregate)

Asphalt Mix Design Using RAP Example Problem

Wt. RAP = 3000 (0.35) = 1050 grams

Wt. CA = 3000 (0.15) = 450 grams

Wt. FA = 3000 (0.46) = 1380 grams

Wt. MF = 3000 (0.04) = 120 grams

3000 grams

Wt. Binder in RAP = 1050 (0.047) = 49.4 grams

Wt. RAP aggr. = 1050 - 49.4 = 1000.6 grams

Asphalt Mix Design Using RAP Example Problem

Total aggr. Wt. = (1000.6 + 450 + 1380 + 120)

= 2950.6 grams

% RAP aggr. =(1000.6 / 2950.6)100 = 33.9

% CA = (450 / 2950.6) 100 = 15.3

% FA =(1380 / 2950.6) 100 = 46.7

% MF = (120 / 2950.6) 100 = 4.1

Asphalt Mix Design Using RAP Example Problem

- Using the previous information, what weight of new asphalt must be added to achieve a total binder content of 4.5% by weight of mix?
- What is the percent added binder by weight of mixture?

Asphalt Mix Design Using RAP Example Problem

- Using the previous information what weight of new binder must be added to achieve a total binder content of 4.5% by weight of mix?

Wt. of total binder = (2950.6 X 100) - 2950.6
100 - % binder
= 139.0 grams

Wt. of new binder=(wt. total binder- wt. RAP binder)

= (139.0 - 49.4) = 89.6 grams

Asphalt Asphalt Mix Design Using RAP Example Problem

- What is the percent added asphalt by weight of mixture?

Wt. Aggregate = 2950.6 grams

Wt. Old binder = 49.4 grams

Wt. New binder = 89.6 grams

Total mix weight = 3089.6 grams

Percent binder added to mixture =
(89.6 / 3089.6) 100 = 2.9%

Asphalt Asphalt Mix Design Using RAP

Questions? Comments?

ND QC/QA Asphalt Concrete Mix Controller

HMA Field Management

Quality Management In the Field

Concerns:

Producing Specification Mixture

Maintaining VMA

Quality Management In the Field

Producing Specification Mixture

FHWA Demo Project #74, *Field Management of Asphalt Mixes.*

1. Start with an approved preliminary design.
2. Account for changes:
   - during stockpiling
   - through the cold feeds and mix plant
   - during discharging mix into haul trucks

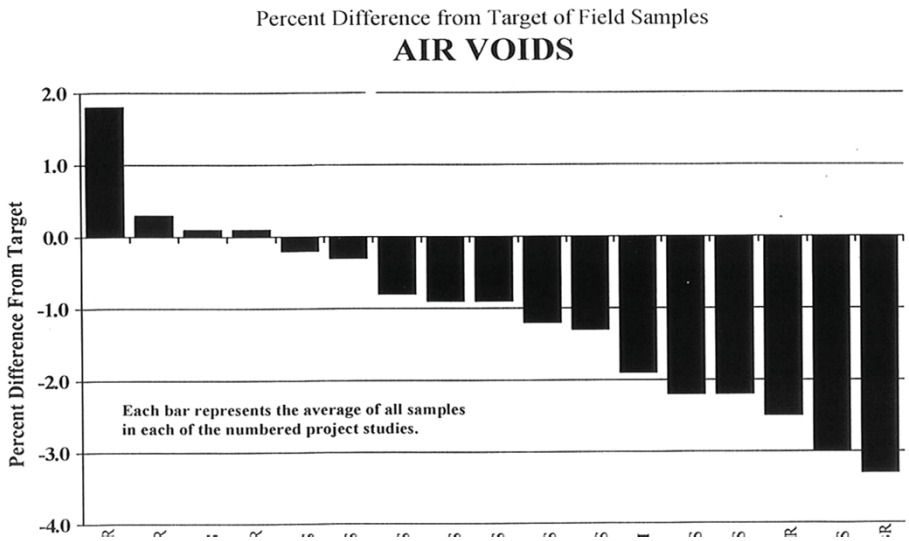
Quality Management In the Field

Producing Specification Mixture

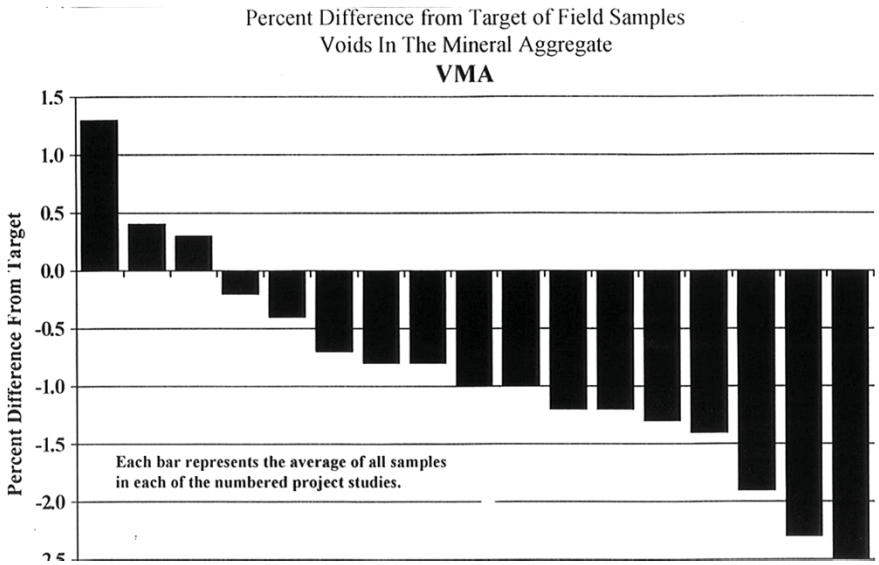
Demo #74

- Introduced “Mix Verification”
- A QC screening technique aimed at determining a mix’s acceptability when compared to the approved design specifications
- FHWA mobile trailers tested plant-produced properties of 17 mixes

Demo 74 – Air Void Changes



Demo 74 - VMA changes



Quality Management In the Field

Producing Specification Mixture

Demo #74

- 2 of 17 met specs -- as produced
- 10 of 17 required mixture adjustments to meet specs
- 5 of 17 mixes had to be redesigned to meet specs

Quality Management In the Field

Producing Specification Mixture

Demo #74

- Study found that there "… is generally some degradation of the aggregate through the asphalt plant …"
- Study showed, on average, plant-produced air voids contents are about 1% less than the originally approved design voids content.

Quality Management In the Field

Maintaining VMA

- Goal: to produce mix like that designed. Demo #74.

- Mix Design:

1. Use representative / actual aggregate
2. Use coarser or more angular intermediate size aggregates
3. Be aware of degradation

Yogi Berra

- "If you always do what you've always done, you'll always get what you always got."

Quality Management In the Field

Maintaining VMA
At the Plant Site

- Monitor consistency of aggregate

    1. Gradation
    2. Specific Gravity and Absorption
    3. Clay Content / Plasticity
    4. Texture

Quality Management In the Field

- Control asphalt binder content and aggregate filler content. Adjust for aggregate degradation.

- Dry aggregate thoroughly.

- Guideline: To increase the VMA, move the gradation away from the max density line.

HOW TO INCREASE VOIDS IN MINERAL AGGREGATE (VMA) OF HOT MIX ASPHALT (HMA)

From: Ad Hoc Mix Design Task Group

Guidelines to Increase VMA of HMA Mixes

- VMA = Air Voids + Eff. Asphalt Content
- VMA allows for sufficient space for adequately thick film of asphalt on the aggregate to provide adhesion and durability
- VMA is controlled by the packing characteristics of the combination coarse,intermediate and fine sized aggregate particles

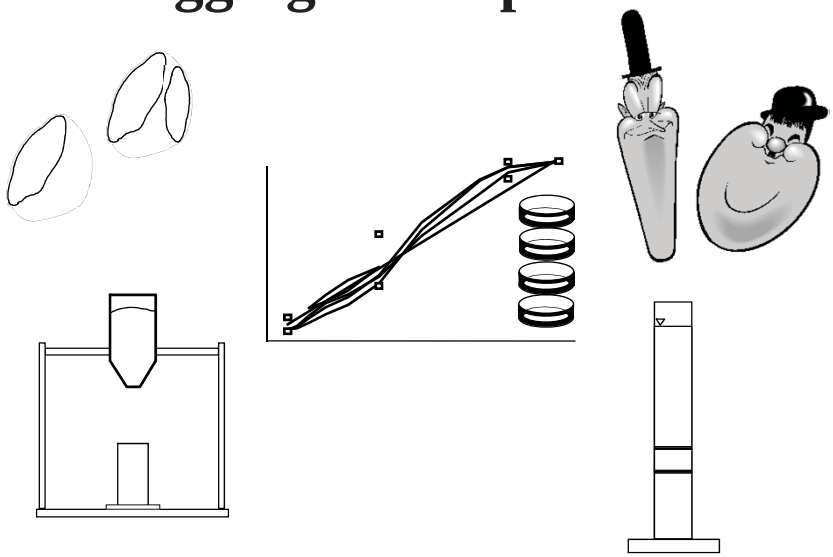
Guidelines to Increase VMA of HMA Mixes

- Most agencies require a minimum VMA during mix design
- Many states require minimum VMA on produced mix
- In certain situations, designers have difficulty obtaining adequate VMA
- When minimum VMA is not obtained, aggregate source, production and/or blending can be changed to improve key properties, which usually results in higher VMA

Guidelines to Increase VMA of HMA Mixes

- VMA is dependent on three major aggregate related factors
  - Aggregate gradation
  - Aggregate surface texture
  - Aggregate shape

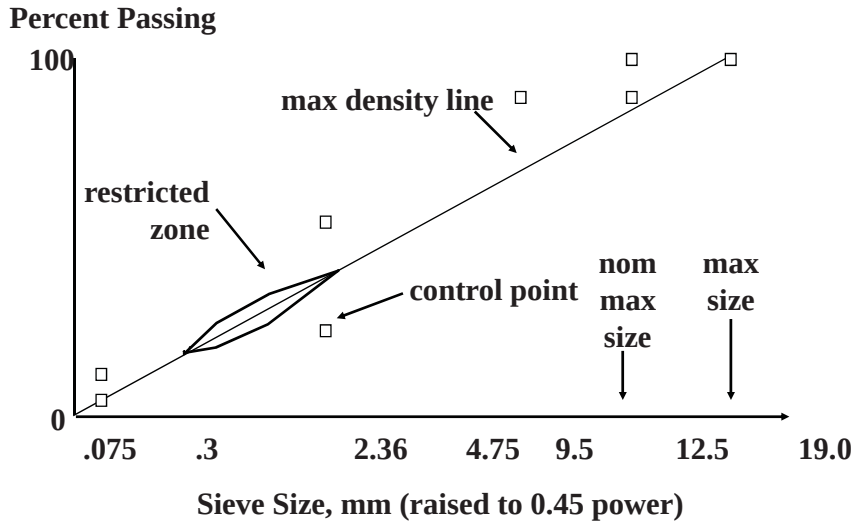
Aggregate Properties



Guidelines to Increase VMA of HMA Mixes

- **Aggregate gradation effect** - changing the particle size distribution can influence the amount of space in the aggregate skeleton. Some ways to change aggregate gradation that may increase VMA are:
  - move gradation on 0.45 curve away from MDL
  - lower the minus #200 content
  - gap grade the gradation
  - rescreen the stockpiles

Gradation



Guidelines to Increase VMA of HMA Mixes

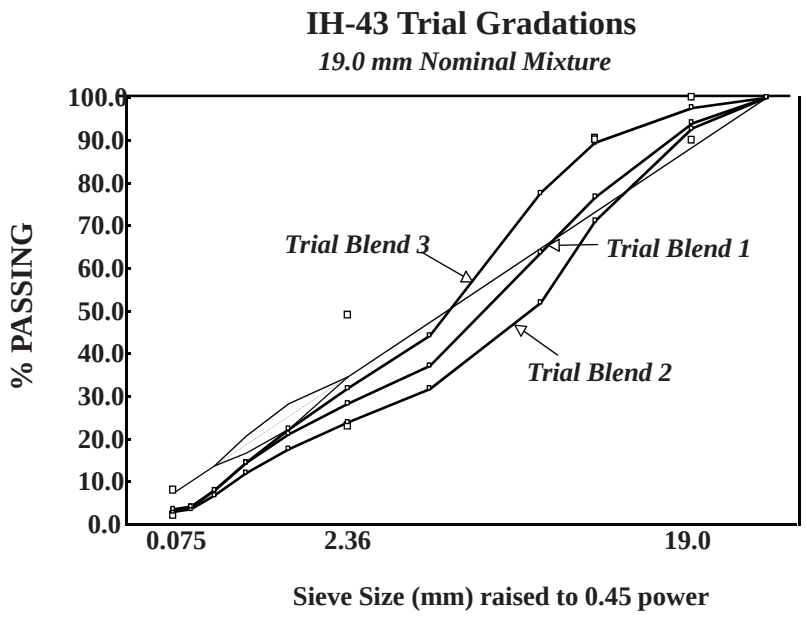
- Aggregate gradation effect
  - move gradation on 0.45 power curve away from Maximum Density Line (MDL)
    - MDL is densest possible blend of coarse, intermediate and fine aggregates
    - adjust blend to create a gradation that deviates either above (finer) or below (coarser) than MDL; this creates space in the void structure

Guidelines to Increase VMA of HMA Mixes

- Aggregate gradation effect
  - lower the minus #200 content - reduce the dust content to lower end of specification limit by reproportioning, washing the fine agg., changing to cleaner sources, reducing the amount of filler

Guidelines to Increase VMA of HMA Mixes

- Aggregate gradation effect
  - Gap grade the gradation
    - create an s-shaped gradation plot
    - this increases the amount of coarse aggregate while reducing the amount of material between the next two sieves
    - **Reason** - there is not enough “intermediate” sized material to fill the space between larger aggregate particles, so VMA is increased



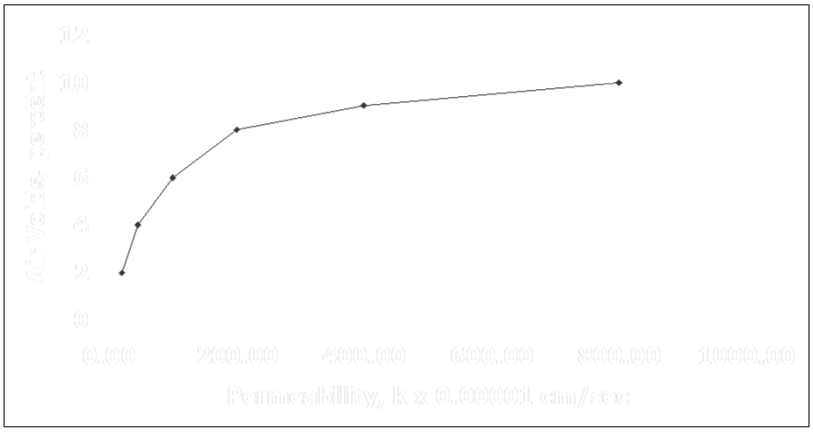
Guidelines to Increase VMA of HMA Mixes

- Aggregate gradation effect
  - Rescreen the Stockpiles
    - Split stockpile to form two or more stockpiles
    - Increases ability to re-proportion the material
    - may be necessary to reject part of source (usually fines or sand)

Guidelines to Increase VMA of HMA Mixes

- Aggr. gradation effect - Caution!!
  - Some coarse graded and gap graded Superpave mixes are difficult to compact
  - these mixes are also prone to be very permeable when low in-place voids (6 to 7% max.) are not achieved during the compaction procedure.
  - <u>Extra effort during compaction to obtain low in-place voids and reduce permeability is critical</u>

Typical Permeability vs. Voids



Guidelines to Increase VMA of HMA Mixes

- Aggr. gradation effect - Caution!!
  - VMA of plant produced mixes can be dramatically lower than design VMA
  - P200 % can be significantly higher in production (aggr. breakdown, addition of baghouse fines)
  - add additional fines to gradation during mix design to anticipate increase in production

Guidelines to Increase VMA of HMA Mixes

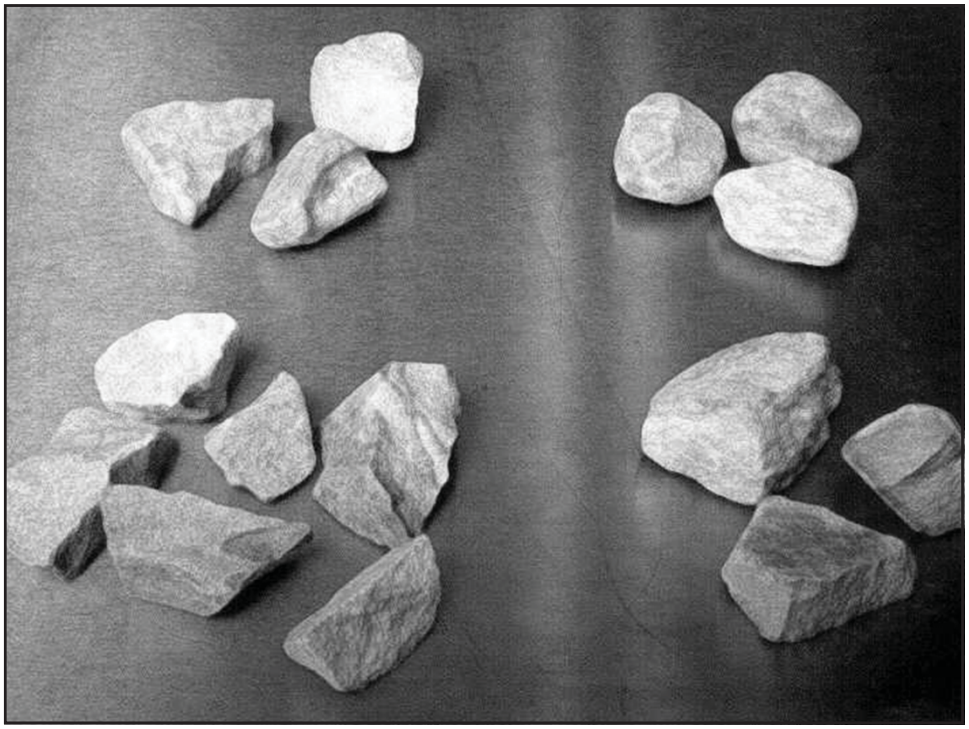
- Aggregate Surface Texture Effect - rougher textured aggregates generate more friction between aggregate particles and resists compaction; when rough surface textures are used, the mix does not compact as much and there is an increase in the amount of space in the aggregate skeleton. Some ways to improve surface texture that may increase VMA are:

Guidelines to Increase VMA of HMA Mixes

- Increase crushed face content of coarse aggregates
  - use coarse aggregate with more crushed faces (especially two-crushed faces)
- Increase manufactured sand
  - replace all or some of the natural sand with manufactured sand, where possible
  - benefits of using manufactured sand may be offset if minus #200 sieve material is increased
  - high FA Angularity numbers (> 45) is one indication of good surface texture

Guidelines to Increase VMA of HMA Mixes

- Aggregate Surface Shape - Cubical particles do not pack as tightly as flat particles (especially when a SGC is being used). Generally, when cubical aggregate are used, there is an increase in the space in the aggregate skeleton and VMA increases. Some ways to improve the shape factor of the aggregate that may increase VMA are:
  - replace some or all aggregates that have a high % of flat and elongated particles

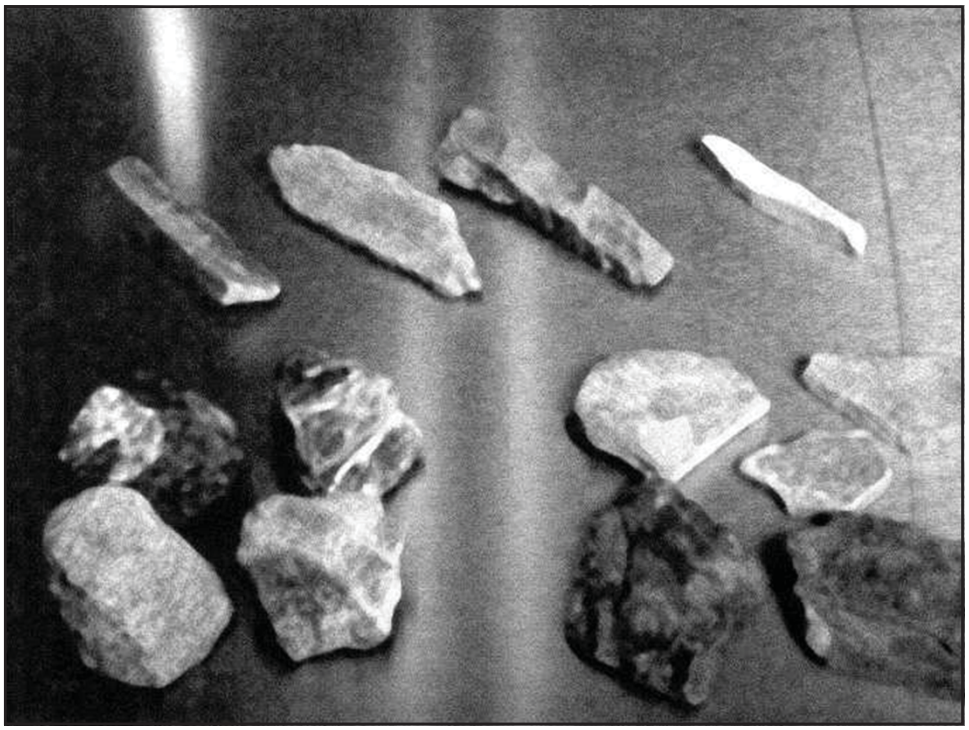


Guidelines to Increase VMA of HMA Mixes

- Aggregate Surface Shape
  - Adding an intermediate aggregate with cubical shape disturbs the larger particles from lying flat. The VMA generally increases. This is especially valuable when the new material is “hard” and/or “insoluble”
    - especially when 100% limestone or other soft aggregate being used in mix
    - hardness can be measured with “Insoluble Residue” test
    - aggregate size - minus #4 plus P200
    - high FAA (>48)

Guidelines to Increase VMA of HMA Mixes

- Aggregate Surface Shape
  - Replace some or all aggregates that have a high % flat and elongated particles
  - crushing operations can have a large effect on F&E numbers. Making changes to crushing operation can produce better shape
  - Look at feed rate, cone settings, etc.
  - vertical shaft impact crushers tend to produce more cubical aggr. than cone crushers
  - If the F&E number for the coarse agg. stockpiles are high, try replacing only one of the coarse aggregate stockpiles at a time with a lower F&E material



Guidelines to Increase the VMA of HMA Mixes Conclusions

- VMA is affected by several different aggregate related factors - gradation, shape and texture
- The designer must understand how each of these factors influence VMA
- This understanding will help the designer decide which materials to use

HMA Field Management

Questions / Discussion ?

DEFINITIONS

Aggregate		
Term	**Identifier**	**Definition**
Absorption		The capacity of an aggregate to absorb water (or asphalt).
Specific Gravity		The ratio between the weight of a given volume of aggregate and the weight of an equal volume of water.
Bulk Specific Gravity	G_{sb}	The ratio of the oven dry weight in air of a unit volume of a permeable material (including both permeable and impermeable voids normal for the material) to the unit weight of an equal volume of water at a stated temperature.
Apparent Specific Gravity	G_{sa}	The ratio of the oven dry weight in air of a unit volume of an impermeable material to the weight of an equal volume of water at a stated temperature.
Asphalt		
Air Voids	P_a or V_a	The total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture.
Voids in Mineral Aggregate	VMA	The volume of inter-angular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the volume of the asphalt not absorbed into the aggregate.
Voids Filled with Asphalt	VFA	The percent of the volume of the Voids in Mineral Aggregate (VMA) that is filled with asphalt cement.
Effective Specific Gravity of Aggregate	G_{se}	The ratio of the oven dry weight in air of a unit volume of permeable material (excluding voids permeable to asphalt) to the weight of an equal volume of water at a stated temperature.
Bulk Specific Gravity of Compacted Mixture	G_{mb}	The ratio of the weight in air of a unit volume of compacted specimen of hot mix asphalt (including permeable voids) to the weight of an equal volume of water at a stated temperature.

Asphalt		
Term	**Identifier**	**Definition**
Theoretical Maximum Specific Gravity (Rice Test)	G_{mm}	The ratio of the weight in air of a unit volume of an uncompacted HMA to the weight of an equal volume of water at a stated temperature.
Effective Asphalt Content	P_{be}	The total asphalt content of HMA less the portion of asphalt binder that is absorbed by the aggregate particles; expressed as a percentage of the total weight of the compacted paving mixture.
Volume of Absorbed Asphalt	V_{ba}	The volume of asphalt binder that has been absorbed into the pores of the aggregate.
Gradation		The distribution of particle sizes expressed as a percent of the total weight of the sample.
Marshall Flow		The vertical deformation of the sample measured from the start of loading to the point at which stability begins to decrease, measured in 1/100 of an inch.
Marshall Stability		The maximum load carried by a compacted specimen tested at 140°F at a loading rate of 2 inches per minute.

EQUATIONS

AGGREGATES

Combining Aggregate Specific Gravities

$$Gsb = \frac{P1 + P2 + \cdots + Pn}{\frac{P1}{G1} + \frac{P2}{G2} \ldots + \frac{Pn}{Gn}}$$

G_{sb} = specific gravity for the total aggregate
P_1, P_2, P_n = individual percentages by weight of aggregate
G_1, G_2, G_n = individual bulk specific gravities of aggregate

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Fine Aggregate Specific Gravity, *(AASHTO T 84)*

$$Bulk\ Specific\ Gravity\ (Gsb) = \frac{A}{B + 500 - C}$$

$$Apparent\ Specific\ Gravity\ (Gsa) = \frac{A}{B + A - C}$$

$$Absorption = \left(\frac{500 - A}{A}\right) X\ 100$$

A = Weight of oven dry sample
B = Weight of flask, cover plate, and water to top of flask
C = Weight of flask, cover plate, sample and water to top of flask
500 g = Weight of saturated surface dry sample in air

Coarse Aggregate Specific Gravity, *(AASHTO T 85)*

$$Bulk\ Specific\ Gravity\ (Gsb) = \frac{A}{B - C}$$

$$Apparent\ Specific\ Gravity\ (Gsa) = \frac{A}{A - C}$$

$$Absorption\ \left(\frac{B - A}{A}\right) X\ 100$$

A = Weight of oven dry sample in air
B = Weight of saturated surface dry sample in air
C = Weight of saturated sample in water

ASPHALT MIXTURES

Effective Specific Gravity of Aggregate

$$Gse = \frac{Pmm - Pb}{\frac{Pmm}{Gmm} - \frac{Pb}{Gb}}$$

G_{se} = effective specific gravity of aggregate (stone)
G_{mm} = theoretical maximum specific gravity of paving mixture (no air voids)
P_{mm} = percent by weight of total loose mixture = 100
P_b = asphalt (binder) content at which test was performed, percent by total weight of mixture
G_b = specific gravity of asphalt (binder)

$$Agg\ Mixture\ Effective\ Specific\ Gravity\ (Gse) = \frac{100 - \%\ AC}{\frac{100}{Max\ Sp.Gr\ Mix} - \frac{\%\ AC}{Sp.Gr\ of\ AC}}$$

(Theoretical) Maximum Specific Gravity *(RICE Test AASHTO T 209)*

$$Gmm = \frac{Pmm}{\frac{Ps}{Gse} + \frac{Pb}{Gb}}$$

G_{mm} = theoretical maximum specific gravity of paving mixture (no air voids)
P_{mm} = percent by weight of total loose mixture = 100
P_s = aggregate (stone) content, percent by total weight of mixture
P_b = asphalt (binder) content at which test was performed, percent by total weight of mixture
G_{se} = effective specific gravity of aggregate
G_b = specific gravity of asphalt (binder)

$$Maximum\ Specific\ Gravity\ (Gmm) = \left(\frac{100}{\frac{\%\ Agg}{Eff\ Sp.Gr\ of\ Aggr} + \frac{\%\ AC}{Sp.Gr\ of\ AC}}\right)$$

Bulk Specific Gravity – of compacted HMA (*AASHTO T 166)*

$$G_{mb} = \frac{A}{B-C}$$

G_{mb} = Bulk Specific Gravity

A = mass of dry specimen (in air)
B = mass of surface-dry specimen in air, g
C = mass of specimen in water, g

Unit Weight/Mix Density of Asphalt Mix = G_{mb} X 62.4

Asphalt Absorption

$$Pba = 100\ X\ \left(\frac{Gse - Gsb}{Gsb\ X\ Gse}\right) X\ Gb$$

P_{ba} = absorbed asphalt (binder), percent by weight of aggregate
G_{se} = effective specific gravity of aggregate (stone)
G_{sb} = bulk specific gravity of aggregate (stone)
G_b = specific gravity of asphalt (binder)

$$Asphalt\ Absorption\ (Pba) = 100\ X\ \left(\frac{Eff.Sp.Gr.Aggr\ - Bulk\ Sp.Gr.Aggr\ Blend}{Eff.Sp.Gr.Aggr\ X\ Bulk\ Sp.Gr\ Aggr\ Blend}\right) X\ Sp.Gr\ of\ AC$$

Effective Asphalt Content of HMA Mixture

$$Pbe = Pb - \left(\frac{Pba}{100}\ X\ Ps\right)$$

P_{be} = effective asphalt content, percent by total weight of mixture
P_b = asphalt content, percent by total weight of mixture
P_{ba} = absorbed asphalt, percent by weight of aggregate
P_s = aggregate (stone) content, percent by total weight of mixture

$$Effective\ Asphalt\ Content\ (Pbe) = \%\ AC - \left(\frac{\%\ Absorbed\ AC\ by\ Wt\ Aggr.}{100}\right) X\ \%\ Aggr$$

Percent VMA in Compacted HMA Mixture

$$VMA = 100 - \left(\frac{Gmb\ X\ Ps}{Gsb}\right)$$

VMA = voids in mineral aggregate, percent bulk volume
G_{sb} = bulk specific gravity of total aggregate
G_{mb} = bulk specific gravity of compacted mixture
P_s = aggregate (stone) content, percent by total weight of mixture

$$Percent\ VMA = 100 - \left(\frac{Bulk\ Sp.Gr.Mix\ X\ \%\ Aggr}{Bulk\ Sp.Gr.Agg\ Blend}\right)$$

Percent Air Voids

$$Va = 100\ X\ \left(\frac{Gmm - Gmb}{Gmm}\right)$$

V_a = air voids in compacted HMA mixture, percent of total volume
G_{mm} = theoretical maximum specific gravity of paving mixture (Rice test – no air voids)
G_{mb} = bulk specific gravity of compacted mixture

$$Percent\ Air\ Voids\ (Va) = 100\ x\ \left(\frac{Theor\ Max.Sp.Gr.Mix - Bulk\ Sp.Gr.Mix}{Theor.Max.Sp.Gr.Mix}\right)$$

Voids Filled With Asphalt

$$VFA = \frac{VMA - Air\ Voids}{VMA}\ X\ 100$$

VFA = Voids Filled with Asphalt, percent of VMA
VMA = Voids in mineral aggregate, percent bulk volume
Corrected Air Voids = air voids in compacted HMA mixture, percent of total volume

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Dust to Asphalt

$$Dust\ to\ Asphalt\ Ratio = \frac{\%\ Passing\ No.200}{Pbe}\ Where$$

$$Eff.AC = \%\ AC - \left(\frac{\%\ Absorbed\ AC\ by\ Wt\ of\ Agg}{100}\right)\ X\ \%\ Agg\ in\ Mix$$

% A.C. from Mix Design at 4% air voids

% Passing No. 200 = Aggregate content passing no. 200 sieve, percent of aggregate weight
P_{be} = effective asphalt content, percent by total weight of mixture
These values are taken from the mix design, at the design asphalt content value.

Mix Design – Batching Aggregates and Liquid Asphalt

Determining asphalt content with given mass of aggregate, and given mass of asphalt.

$$Percent\ AC = \left(\frac{Weight\ of\ Asphalt}{Weight\ of\ Aggregate + Weight\ of\ Asphalt}\right)100$$

Determining weight of asphalt cement needed for a target AC content.

$$Weight\ of\ Asphalt\ Cement = \left[\frac{weight\ of\ aggregate}{100 - Target\ AC\ Content} X\ 100\right] - Wt\ aggregate$$

SUMMARY OF DEFINITIONS AND CONVENTIONS

NAMING CONVENTIONS

G_{sb}

volumetric property ↗ | material ↑ | type ↖

G = specific gravity	s = stone	b = bulk
V = volume	b = binder	e = effective
P = percent	m = mix	m = maximum theoretical
	a = air	a = apparent (for G) or
		a = absorbed (for V and P)

DEFINITIONS

G = specific gravity
G_b = specific gravity of binder
G_{sb} = bulk specific gravity of aggregate
G_{se} = effective specific gravity of aggregate
G_{sa} = apparent specific gravity of aggregate
G_{mb} = bulk specific gravity of mix
G_{mm} = maximum theoretical specific gravity of mix

V = volume
V_a = volume of air voids
V_{ba} = volume of binder absorbed
V_{be} = volume of effective binder

P = percent
P_a = percent air
P_s = percent stone ($100 - P_b$)
P_b = percent binder
P_{ba} = percent binder absorbed
P_{be} = percent effective binder
$P_{0.075}$ = percent passing 0.075 sieve