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HOT MIX ASPHALT MIX DESIGN CERTIFICATION

VERSION 18.0

Division of Materials and Tests 2018

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Helpful Links

Specs, Circulars, Etc:	https://www.tn.gov/tdot/tdot-construction-division/transportation-construction-division-resources/transportation-construction-2015-standard-specifications.html
SOP:	https://www.tn.gov/tdot/materials-and-tests/standard-operating-procedures.html
Blank Forms:	https://www.tn.gov/tdot/materials-and-tests/field-operations/forms.html
Training Information:	https://www.tn.gov/tdot/materials-and-tests/field-operations/training.html

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Introduction

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TDOT Asphalt Mixture Design Workshop

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ADA Notice of Requirements

- Can be found at the following website:
  - http://www.tn.gov/tdot/topic/transportation-americans-with-disabilities-notice
- To be in compliance with TDOTs requirements listed on the website above, it is our goal to provide reasonable accommodations to those who identify themselves as having a disability and request such accommodations.
- Please feel free to bring it to any of the course instructors and accommodations will be administered as discretely as possible.

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No Tobacco Related Product Inside Building!!!!!!!!!!!!!

No Electronic Cigarette
No Chewing Tobacco Allowed
Spitting into a bottle disturbs others

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Mix Design Workshop

- Workbook Description
  - General Information
  - Definitions/Abbreviations/Formulas
  - Standard Test Methods Specs
  - TDOT Specs/Applicable Supplemental Specs
  - Sample Job Mix Formula (JMF)

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Mix Design Workshop

- Lecture
- Hands-on Demonstration
- Performing Calculations
- Test (Half Day)
  - Test Methods
  - Specifications/Results Interpretation

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Mix Design Workshop

- Contacts for demonstration at the Regional Laboratories:
  - Region 1: Billy Goins (865) 806-1935
  - Region 2: Tony Renfro (423) 510-1190
  - Region 3: Jody Wright (931) 841-7961
  - Region 4: Mitch Blankenship (731) 935-0231

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Why have a mix design course?

- Contractor is responsible for performing mix designs
- Federal Regulations (CFR 637) requires the State maintain a Quality program which includes laboratories and technicians
- QUALITY!!

Asphalt Mix Design Technician


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Asphalt Plant Technician


TN TDOT Department of Transportation
Asphalt Roadway Technician

Requirements for Mix Design Certification

- Pass Exam, 70% or better.
- Perform a Full Mix Design Demonstration at Regional Lab
- Regional TDOT personnel will mail documentation of your passed demo to Nashville (HQ).
- HQ personnel will mail your certificate and card with your certification number to the address you provided here on the sign-up sheet.

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Requirements for Mix Design RE-Certification

- Certifications last 5 years
- To Re-certify, you must attend a one-day, regional re-certification class *BEFORE* your certificate expires. Then, you must do a small re-cert demo at the region.
- Regional TDOT personnel will mail documentation of your passed re-cert demo to Nashville (HQ).
- New cards and certs will be mailed out as before.

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Abbreviations

- The final page at the end of the book contains all abbreviations.

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Basic Materials

Basic Materials

The Basic Recipe

Ingredients:

- Asphalt Cement (binder) ~ 95%
- Aggregate (stone) ~ 5%
- Additives (Anti-Strip) trace

For Mix Design: Pb+ Ps = 100

Pb = % Binder

Ps = % Stone

The Basic Recipe

Step 1: Heat AC until it becomes a viscous liquid and mix in chemical additive.

Step 2: Combine ingredients and mix until aggregate is coated in AC

Step 3: Spread Mixture on Roadway

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The Basic Recipe

Does that sound familiar?

Maybe like something you learned to cook as a kid?

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The Basic Recipe

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The Basic Recipe

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Asphalt Cement

Asphalt Cement

- ~5% of mix
- Glue / Binder
  - Resists tensile force
  - Holds aggregate together
- Little Compressive Strength
  - Does not resist compaction well

Why use Asphalt?

Early roads were just stone, what could go wrong???

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Why use Asphalt?

People began to use other materials to glue, or bind, the stone together, two solutions became the norm.

One of the solutions was Tar, thus Tar-Mac, the term still commonly used for airports.

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Why use Asphalt?

Asphalt soon replaced, tar. Why?

- Asphalt has more favorable properties for production and durability.
- Availability: Asphalt is a byproduct of petroleum production.
  - More Cars = More Pavement but also
    More Cars = More Petroleum Production

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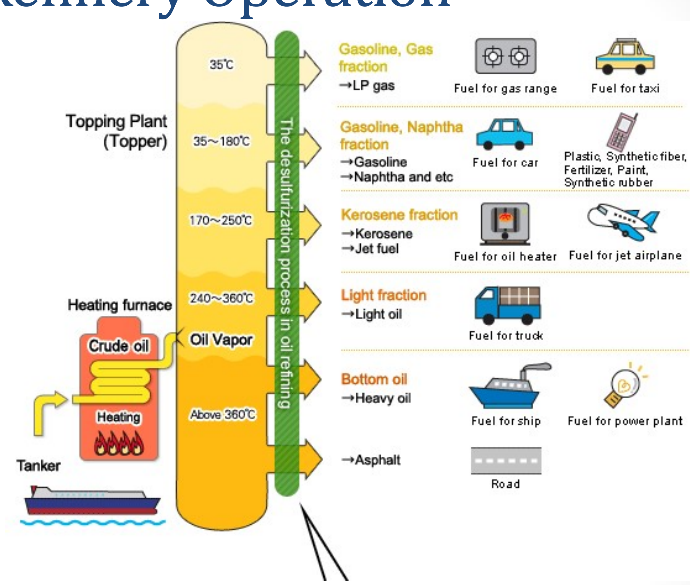
Refinery Operation



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How Asphalt Behaves

Viscoelastic material: i.e. a material with both solid and liquid properties

LOW	*TEMPERATURE*	*HIGH*
SOLID	*APPARENT STATE*	*LIQUID*

HIGH	*VISCOSITY*	*LOW*
HIGH	*ELASTICITY*	*LOW*

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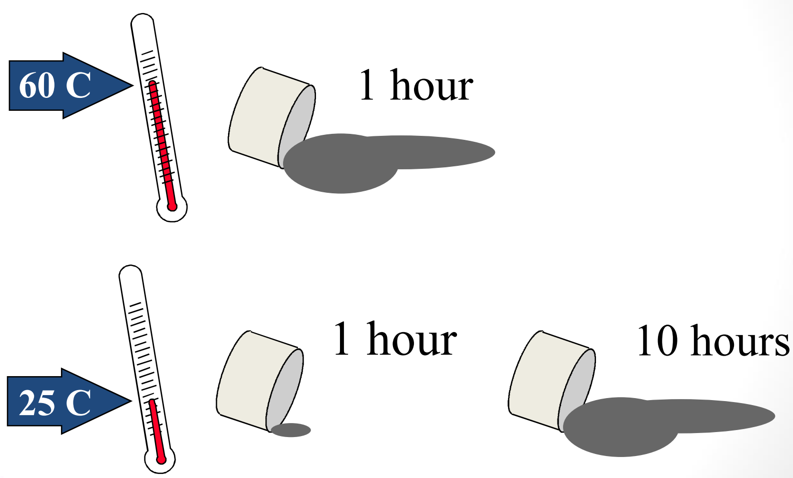
Effect of Temperature



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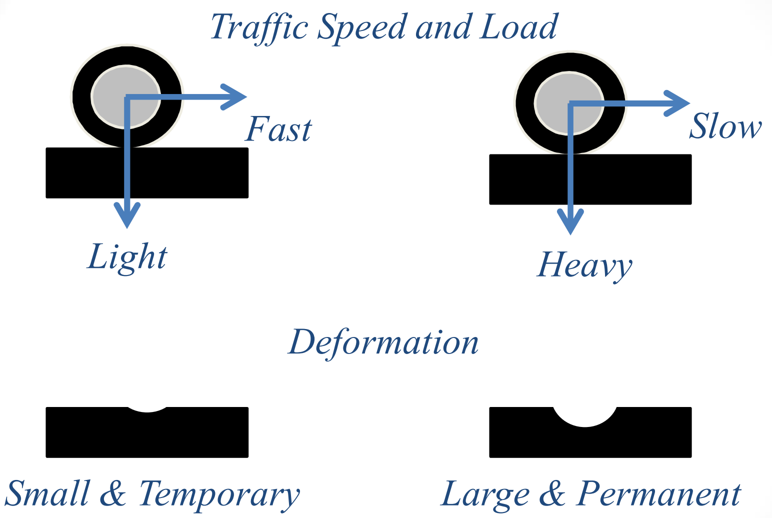
Effect of Loading



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Rutting

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Aging Behavior

- Asphalt Reacts with Oxygen
  - "Oxidative" or "Age" hardening
- During Construction - Short Term
  - Hot mixing
  - Placing/Compaction
- In Service - Long Term
  - Hot climate worse than cool climate
  - Summer worse than winter

BLUE SMOKE!!

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Pavement Behavior

- Aged pavement
  - Harder
  - Less Flexible = More Brittle
- Eventually will happen, goal of mix design is to put this off as long as possible
- Controlled by binder properties

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PG Asphalt Binder Spec

- Grading System Based on Climate

PG 64-22

Performance Grade

Average 7-day max pavement design temp

Min pavement design temp

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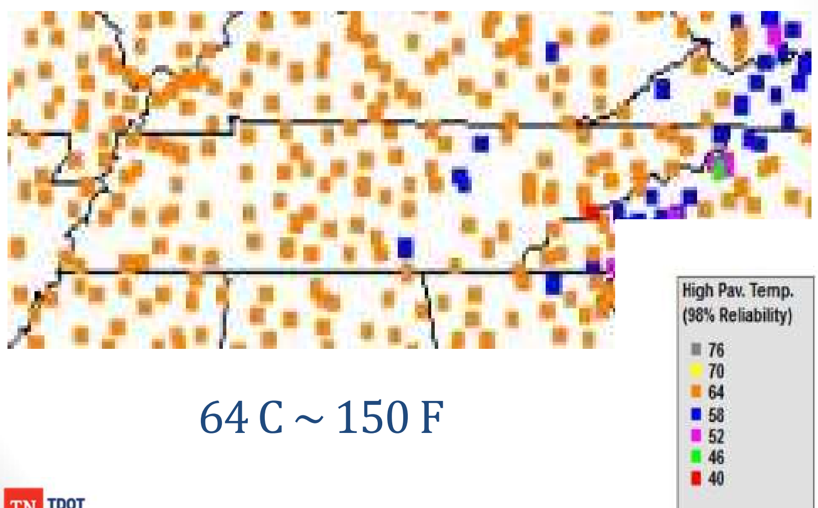
PG Asphalt Binder Spec



64 C ~ 150 F

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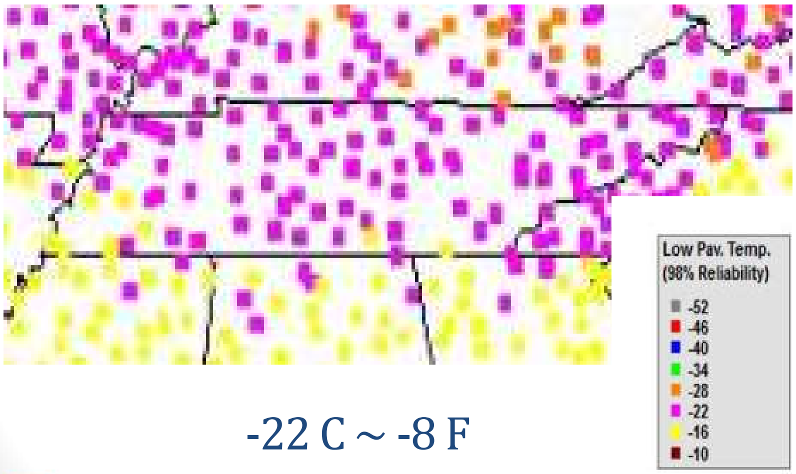
PG Asphalt Binder Spec



-22 C ~ -8 F

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Effect of Traffic Level on Binder Selection

- Asphalt also deforms because of loading
  - Heavier and Slower traffic cause more deformation than Faster and Lighter
- Account for traffic loading by “grade bumping” the high temp to a stiffer AC
- TDOT specifies on plan which grade

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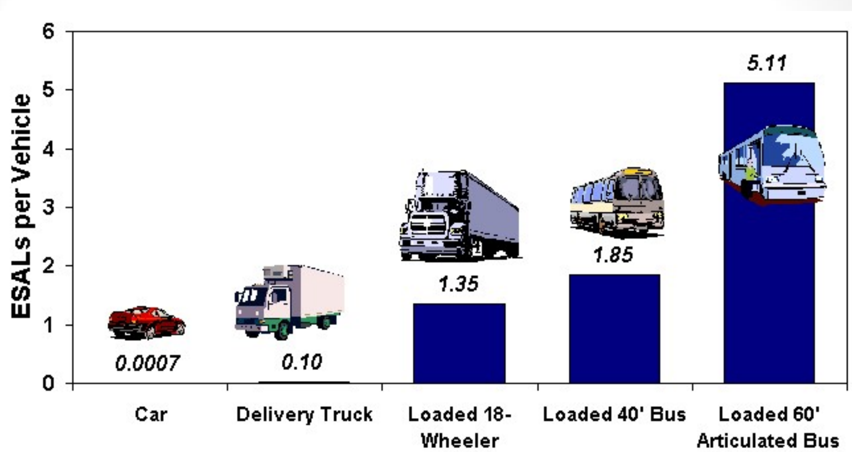
Effect of Traffic Level on Binder Selection

- Measured in ESALs
  - Equivalent Single Axle Load = 18 kips
  - Cumulative over life (20 years)
- General Guidance
  - 10,000 – 30,000 ESALs: bump one grade
  - >30,000 ESALs : bump two grades



TDOT Design Guide 4-300.00

- PG 64-22 on SR up to 10,000 ADT
- PG 70-22 on SR above 10,000 ADT
  - Also always on SR15, SR5, SR43, SR22
- PG 76-22 on Interstates
  - Maybe on SR in Special Cases
- PG 82-22 special case only (heavy truck traffic/slow traffic/intersection)

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"Rule of 90"

(More like a guideline!)

- Balance Between High and Low Temp Physical Properties
  - Absolute difference between high and low temp grade
  - Difference < 90 probably unmodified asphalt
  - Difference > 90 probably modified asphalt
- PG 64-22
  - Difference = 64 - - 22 = 86
  - Probably unmodified
- PG 70-22
  - Difference = 70 - - 22 = 92
  - Probably modified

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Modifiers

Ref: TDOT spec. 904.01

- If modification of the asphalt is necessary that will be accomplished by blending the following modifiers:
  - Styrene Butadiene (SB)
  - Styrene Butadiene Styrene (SBS)
  - Styrene Butadiene Rubber (SBR)
  - Ground Tire Rubber (GTR)

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How Grades Effect Mix Design

- Modified binders: more expensive
  - 92 degree differential -> 5% more expensive
  - 98 degree differential -> 15% more expensive
- Modified binders: stiffer, have to be heated more to get to desirable viscosity for mixing/compaction

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Asphalt Binder Lab Temperatures

Ref: TDOT Spec. 407.03-1

Table 407.03-1: Laboratory Mix and Compaction Temperatures

PG Binder Grade	Lab Mix Temperature (°F)	Lab Compaction Temperature (°F)
64-22, 67-22	Per temp./visc. chart	Per temp./visc. chart
70-22	320 – 345	295 – 320
76-22	320 – 345	305 – 330
82-22	320 – 345	305 – 335

Perform any additional laboratory testing of the mix using the laboratory mix and compaction temperatures listed on the approved JMF, with a tolerance of ± 5 °F for each temperature.

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Viscosity

Measurement of a fluid's resistance to flow.

Household Liquids at 70 F

Water = 1 cSt

Whole Milk = 4 cSt

Honey = 2200 cSt

Molasses = 10,000 cSt

Asphalt (300 F) = 170 cSt

Asphalt (275 F) = 300 cSt

Asphalt (70 F) = 230,000,000,000 cSt

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Temperature Viscosity Curve

- The temperature at which the viscosity is **170 ± 20 cSt** is used to select the **Mix** temperature.
- The temperature at which the viscosity is **280 ± 30 cSt** is used to select the **Compaction** temperature.
- Conversions are the most difficult part of this process, because Temp/Visc charts aren't always in the same units.

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Viscosity Conversions

	Centistokes (cSt)	Poise	Pascal Seconds (Pa*s)
Mix	170 ± 20	1.7 ± 0.2	0.17 ± 0.02
Compact	280 ± 30	2.8 ± 0.3	0.28 ± 0.03

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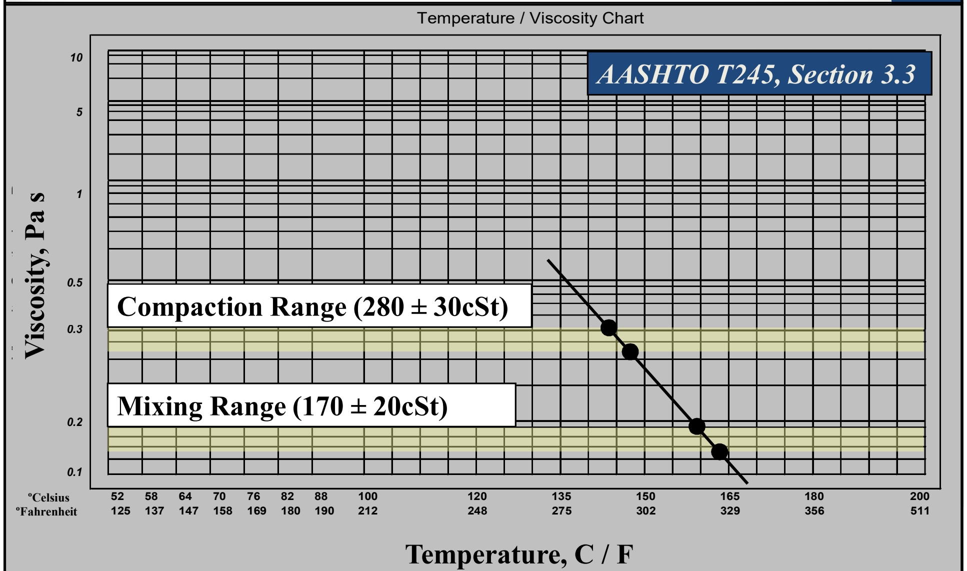
Mixing/Compaction Temperatures



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Mix Temperature: Plant Production Temp.

- Must adhere to TDOT Spec 407.11

Table 407.11-1: Mixing Temperatures

PG Binder Grade	Minimum Temperature (°F)	Maximum Temperature (°F)
PG 64-22, PG 67-22	270	310
PG 70-22	290	330
PG 76-22	290	330
PG82-22	290	330

Minimum temperature for OGFC mixes shall be 280°.

The temperature for Grading AS, Grading ACRL, and Grading TPB mixtures shall be between 225 and 275 °F, except when modified binders are used, and then the temperatures shall be between 250 and 310 °F. Aggregate should be coated and no visible drain down should occur in storage silos or hauling equipment.

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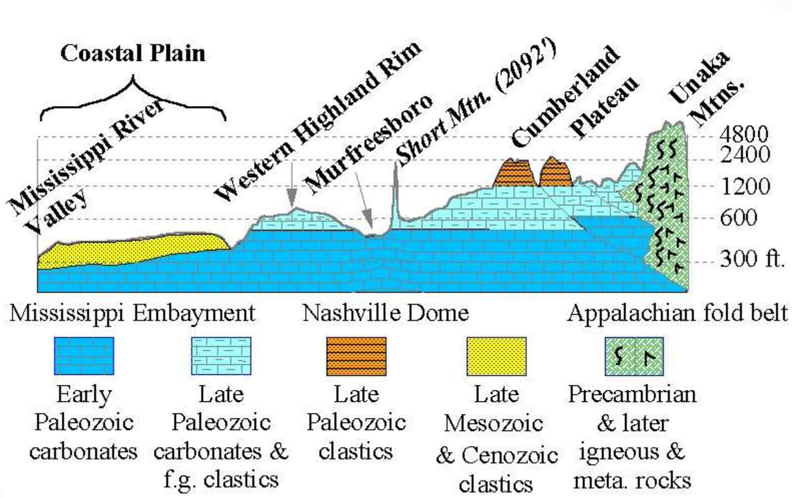
Aggregates

Aggregate

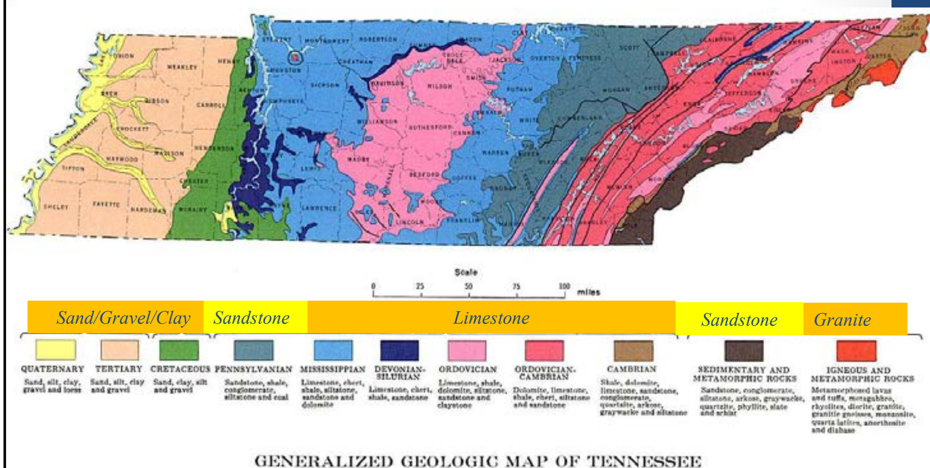
- ~95% of mix
- Structural Skeleton
  - Resists compressive force
  - Provides stability
- No Tensile Strength
  - Cannot be stretched

Aggregate Sources

Aggregate Sources



Aggregate Sources



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Aggregate Processing

Before we can use the aggregate we first must:

- Excavate
- Transport
- Crush
- Size

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Excavation

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Excavation

Above the Fall Line (East of the River)

- Blasted from quarry: creates rough surface, 100% angular.
- Highly Angular: rough surface -> more friction between particles

- Coarse: Crushed Stone
- Fine: Manufactured Sand

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Excavation

Below the Fall Line (West of the River)

- Round: smooth surface -> less friction between particles
- Has to be crushed or roundness otherwise accounted for in design

- Coarse: Crushed Gravel
- Fine: Natural Sand

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Transporting Aggregate

Where are asphalt plants usually located?

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Transporting Aggregate

Transporting Aggregate

Transporting Aggregate

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Transporting Aggregate

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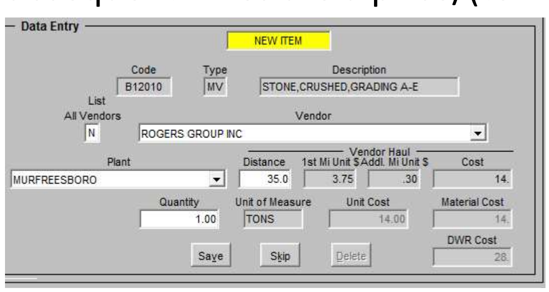
Transporting Aggregates

If there is a quarry, that is where you will find the asphalt plant. Why?

Transporting Aggregate

Haul costs by truck are very expensive

- Typically: 1st mile is a flat fee/(ton)
- All subsequent miles are a price/(ton-mile)



Example: TDOT Maintenance on-call Price

Transporting Aggregate

Aggregate Price = $14

Haul Price = 3.75/ton (1st mile) + $0.30/(ton-mile)

$14(1T) = 3.75/ton(1T) + 0.30/(T-mi)(1T)(X-1 mi)

X=(14-3.75)/0.30 + 1

X= 35 mi

So: at 35 miles you are paying more for hauling than materials.

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Transporting Aggregate

Hauling economics drive using as near as local aggregate as possible.

Ideally you want to use angular stone but…

If all you have nearby is river gravel, that is what you are probably going to have to use.

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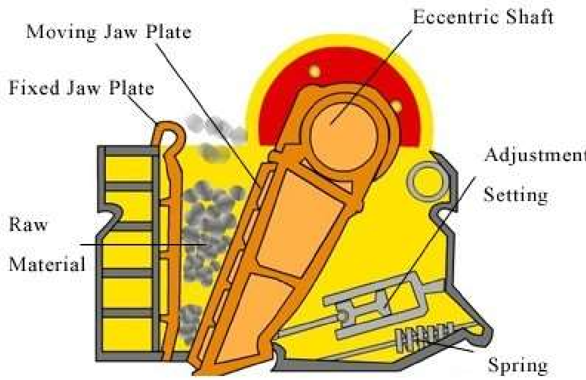
Crushing

Crushing and Sizing

After excavating rock, it still requires further processing, crushing, prior to our use.

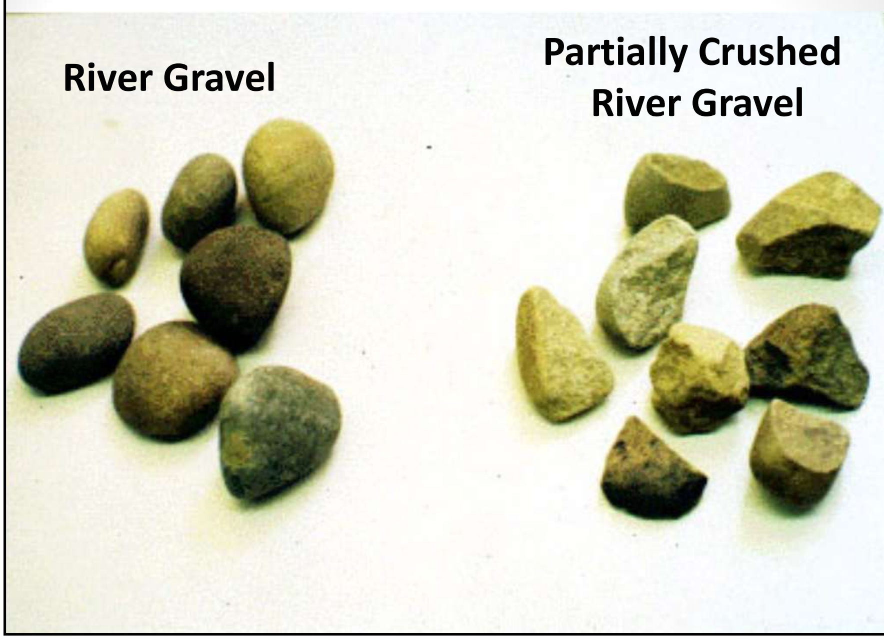
- Gravels: give rough surface and make them more angular
- All: reduce to a desired size

Crushing and Sizing



Jaw Crusher Sectional Drawing

Crushing



Crushing and Sizing

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Crushing and Sizing

- After crushing, aggregates are ran across screens to sort by size.
- Stones of like size are then stockpiled.
  - Defined by nominal aggregate size but will contain particles smaller.
  - Nominal Aggregate and Nominal Maximum Aggregate Size terminology is slightly different when talking about stockpiles aggregate vs asphalt.

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Stockpiling

Stockpile Management

- Prevent segregation and contamination.
- Good Stockpiling = Reliable Gradations
- Best Practices:
  - Short Drop Distances (limits segregation)
  - Minimize Moving (limit cross contamination)
  - Separate Stockpiles (safety/cross contamination)

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Stockpile Management

Sample:

- Evaluate quality of aggregate source.
- Determine/check gradation of each stockpile
  - Building block of mix, need to know for sure you get what you think you are using.

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Aggregate Properties

- Source Properties: Properties that are fairly uniform for rock from the same source
- Consensus Properties: Properties that are dependent on aggregate processing.
  - "Consensus" because state DOTs agreed they were important to the mix design.

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Source Aggregate Properties

- Toughness
- Soundness
- Deleterious Materials
- Gradation

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Toughness

- Resistance of course aggregate to abrasion and mechanical degradation during handling, construction, and use.
- LA Abrasion Test (AASHTO T-96)
  - Aggregate at standard gradation subjected to damage by rolling with a prescribed number of steel balls in large drum for a given number of rotations.
  - Result expressed as a percent change to original weight.

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LA Abrasion Test

- Approx. 10% loss for extremely hard igneous rocks.
- Approx. 60% loss for soft limestones and sandstones.

Soundness

- Estimates resistance to weathering.
- AASHTO T 104 “Sodium Sulfate Soundness Test”
  - Simulates freeze/thaw action by successively wetting and drying aggregate in a sodium sulfate or magnesium solution.
  - One immersion and drying is considered one cycle.
  - Result is total percent loss over various sieve intervals for a prescribed number of cycles.
  - Mass loss values typically fall between 10% to 20% per 5 intervals.

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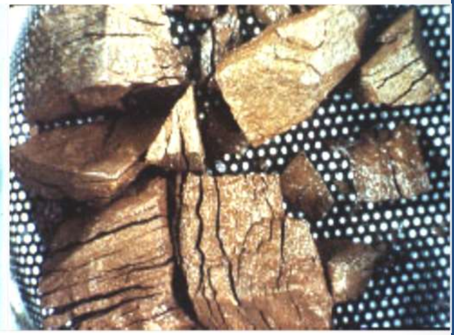
Soundness

Before



After

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Gradations

- Aggregate Gradation
  - The distribution of particle sizes expressed as a percent of total weight.
  - Determined by a sieve analysis.

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Steps in Gradation Analysis

- Part 1 - Washed Sieve Analysis
  - Dry aggregate and determine mass
  - Wash and decant water through 0.075 mm sieve until water is clear
  - Dry aggregate to a constant mass
- Basically attempting to catch as much dust as possible, as it tends to stick to large particles and will through off results.

Steps in Gradation Analysis

- Part 2 – Mechanical Sieve Analysis
  - Place dry aggregate in standard stack of sieves
  - Place sieve stack in mechanical shaker
  - Determine mass of aggregate retained on each sieve
  - Add the mass loss from the part 1 to the weight retained in the pan

Mechanical Sieve

Individual Sieve

Stack of Sieves

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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.

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Aggregate Size Definitions

Sieve (in)	% Pass
3/4"	100
5/8"	100
1/2"	97
3/8"	84
No.4	57
No.8	43
No.16	
No.30	25
No.50	10
No.100	6
No.200	4

- What would be the NMAS for the blend shown here?

  The first step: Find the first sieve to retain more than 10% (aka – less than 90% passing)

→ The NMAS for this blend is ½ inch.

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Aggregate Size Definitions

Sieve (in)	% Pass
3/4"	100
5/8"	100
1/2"	97
3/8"	84
No.4	57
No.8	43
No.16	
No.30	25
No.50	10
No.100	6
No.200	4

What would be the Maximum Aggregate size?

NMAS

Max. Aggregate Size

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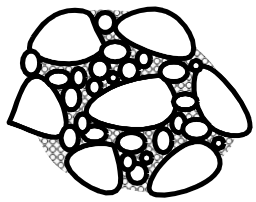
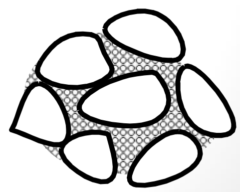
Types of Gradations

- *Uniformly-Graded*
  - *Few points of contact.*
  - *Poor interlock (Shape dependent).*
  - *High permeability.*

- *Well-Graded*
  - *Good interlock.*
  - *Low permeability.*



- *Gap-Graded*
  - *Only limited sizes.*
  - *Good interlock.*
  - *Low permeability.*



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Consensus Aggregate Properties

- Coarse Aggregate Particle Shape
  - Percent Crushed Faces
  - Flat and Elongated
- Fine Aggregate Particle Shape
- Deleterious Materials

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Consensus Aggregate Properties

- TDOT Tests:
  - coarse aggregate crushed faces
  - coarse aggregate flat/elongated
  - deleterious materials
- TDOT does not test:
  - fine aggregate angularity
    - limits natural sand by method spec instead

Percent Crushed in Gravels

- Crushed Faces AKA Fractured Faces
- Quarried materials always 100% crushed.
- Minimum values depended upon traffic level and layer.
- Defined as a percent by count with a required number of crushed faces of the aggregate
  - Required number of fractured faces is spelled out in each spec

Percent Crushed in Gravels

Grading OGFC. A minimum of 75% of the aggregate shall meet the requirements specified in **903.24** for Surface Mixtures (Non-Skid Aggregates). The coarse aggregate shall have at least 90% crushed aggregate with two fractured faces and 100% with one fractured face as determined in accordance with ASTM D5821. The coarse aggregate shall have a LA Abrasion value of less than 40% and a maximum absorption of 3.0%.

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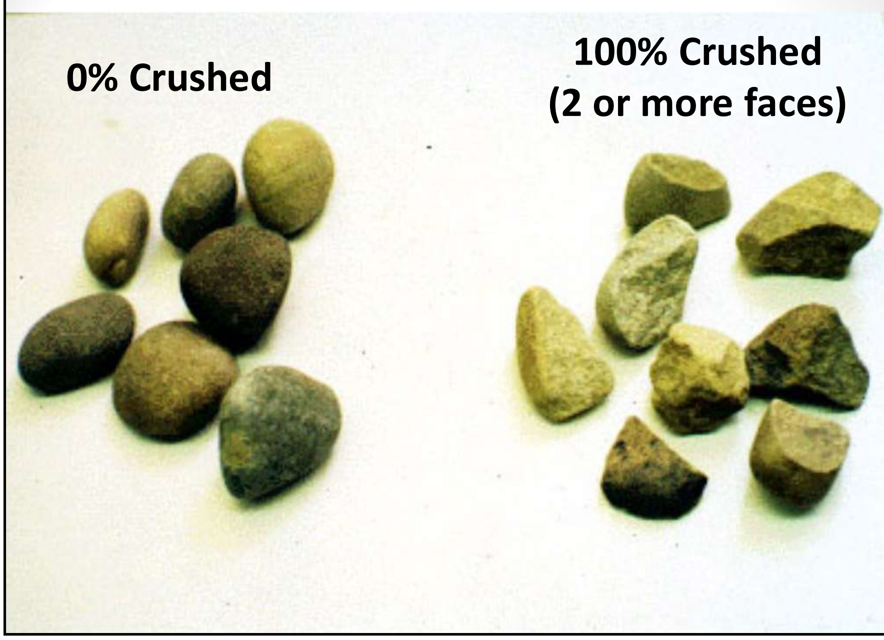
Percent Crushed in Gravels



Flat and Elongated Particles

Does the rock pass the sieve?

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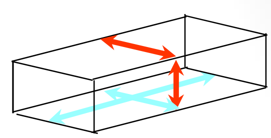
Flat and Elongated Particles

- ASTM D4791
  - Flat and Elongated
  - Total Flat and Elongated
  - Fails if longest dimension is 5 times the average thickness.



Why do we care?

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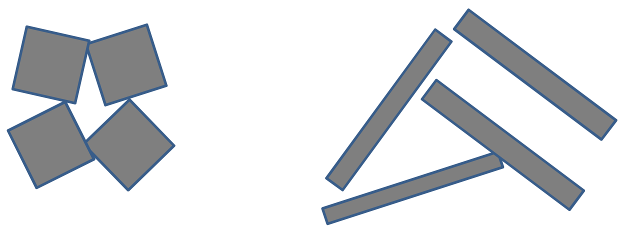
Flat and Elongated Particles



Which is easier to break?

Which is easier to compact?

Flat and Elongated Particles

Rocks that are close to uniform in dimension:

- Orientation doesn’t matter
- All axis are equally strong

Rocks that have widely different dimensions:

- Behavior is reliant on orientation
- Has a weak axis that can be more easily broken

Deleterious Materials

Check for materials present in the stockpile other than aggregate that is harmful to the mix

- Particularly concerned with natural sand
  - Why?
- Checked by independent lab

Table 903.11-1: Limits of Deleterious Substances in Natural Sand used in Hot Mix

Substance	Maximum Permissible Limits Percent by Weight
Clay Lumps	0.5
Coal and Lignite	0.5
Other deleterious substances (such as shale, alkali, mica, coated grains, soft and flaky	3.0

Basic Volumetrics

Quick Refresher from Plant Tech Class

- Volume
- Density
- Specific Gravity

Volume

The amount of space an object occupies

For solid objects: fairly straight forward equations exist

For objects that are not solid: a bit more work to do

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Volume

The easiest way to measure a non-solid object is to submerge it in water and measure the displacement.

The amount of volume displaced is equal to the volume of the object.

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Volume

Why do we care?

What does TDOT want from the contractor?

- Pave a road “X” thick by “Y” wide by “Z” long
- In other words a volume of asphalt

How does TDOT Estimate and Pay for asphalt?

- By the ton
- Which is a mass, not a volume

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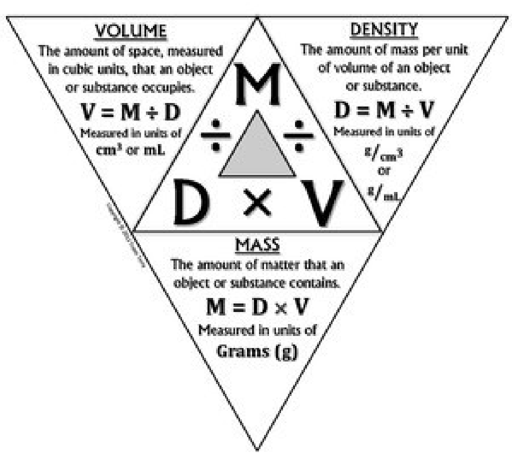
Volume Density Mass Relationship

How do we get from volume to mass (weight)



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Density

- Density is the unit weight of a material
  - lb/ft^3 or kg/m^3

$\gamma_w = 1.000$ g/mL $\quad \gamma_w = 62.4\ lb/ft^3$

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Density

Unfortunately, we don't know what the density of the materials is:

- Aggregate varies based on source and even can change inside the same quarry. Must be verified for each mix design
- AC is more constant and the supplier will supply.

Fortunately, the relative density of aggregate to the weight of water is easy to determine.

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Density

Remember: Density = Mass/Volume

Can determine Volume by displacement but can use easier way…

The buoyancy force from a fluid is:

$F = \gamma_w$ X Vol Displaced

In metric units: Buoyancy(g) = 1 g/ml X Vol (ml)

Density

Since the density of water is 1 we can use grams and mL interchangeably and actually measure volume by determining the change in weight while submerged

Mass dry – mass sub = buoyant force

Mass dry – mass sub = volume

Density = mass/vol

Density = dry mass/(mass dry- mass sub)

Specific Gravity (G)

- Ratio of the density of a material to the that of water for equal volumes.
- Specific gravities are always expressed to three decimal places.

$$G = \frac{\textit{Density of Material}}{\textit{Density of Water}}$$

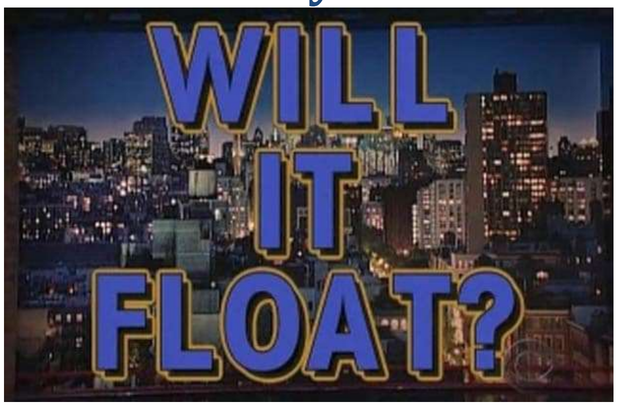
Specific Gravity (G)

$$G = \frac{\textit{Density of Material}}{\textit{Density of Water}}$$

$$G = \frac{\textit{Mass/Vol of Material}}{1\ g/cm^3}$$

- *Using metric units we can simply divide the mass/volume of the material*

Specific Gravity



- If G <1.000 it will float
- If G >1.000 it will sink

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Bulk Specific Gravity, Dry

G: Specific Gravity → ***Gsb***

Material:
s: stone (aggregate)
b: binder (asphalt cement)
m: mix

Type of Specific Gravity:
m: maximum density
b: bulk
a: apparent
e: effective

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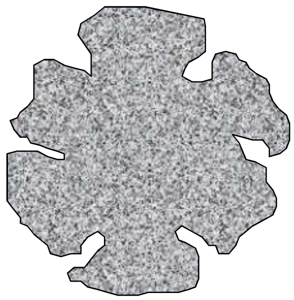
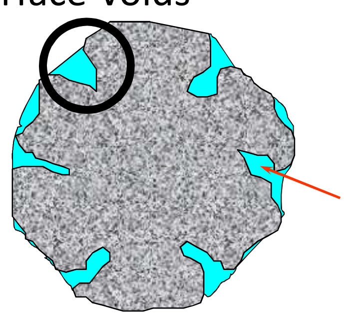
Apparent Specific Gravity



$$G_{sa} = \frac{\text{Mass (Oven Dry)}}{\text{Volume of Agg.}}$$

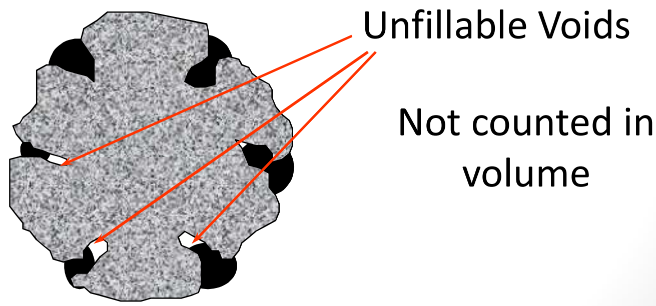
Bulk Specific Gravity

$$G_{sb} = \frac{\text{Mass (Oven Dry)}}{\text{(Volume of Agg. + Surface Voids)}}$$



Effective Specific Gravity

$$G_{se} = \frac{\text{Mass (Oven Dry)}}{\text{(Volume of Agg. + Fillable Voids)}}$$



3

Designing TDOT Mixes

Designing TDOT

Asphalt Mix Designs

Designing a TDOT Mix

- In this section, we will briefly discuss the asphalt mix design process. This is a basic summary to provide an overall understanding of the process. Later, we will discuss each step in more detail.

What Types of Mixes are there?

- Base/Intermediate Mix – Section 307
  A, AS, ACRL, B, BM, BM2, C, CS, & CW
- Treated Permeable Base – Section 313
  TPB
- Surface Mix – Section 411
  D, TL, TLD, OGFC, E, E (Shoulder)

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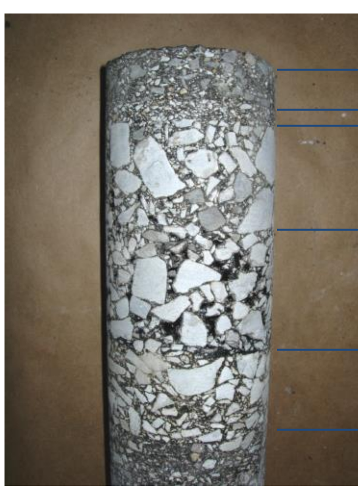
Common TDOT Pavement Structure



411-D Surface Mix
307-CS Leveling Course
307-BM2 Base
307-A Base
307-AS Sub-base

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What Types of Mixes Require a Design?

- Not all TDOT mixes require a design, just paperwork.
- Mixes that require a design are listed in TDOT Standard Operating Procedure 3-4, “Submittal and Approval of HMA Designs.”

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SOP 3-4
“Submittal and Approval of HMA Designs”

- Mixes Requiring Design:
  - BM, BM2, C, CS, CW, D, TL, TLD, OGFC, E (Roadway), E (Shoulder)
- Everything else – Paperwork only
- “Unless otherwise directed by the regional materials supervisor.”

  → Some of the mixes listed here may not require designs in your region.

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Asphalt Binder

- Also known as AC, liquid, binder, tar, oil, and many other names.
- Binder Types are typically designated by their Performance Grade (PG Grade).
  - Also, by MSCR designations
- The grade required for your design will be specified in the contract.

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Asphalt Binder

- Shipments of AC will be accompanied by a barge certificate. This contains lots of important info about the AC you are using, such as:
  - Source
  - Asphalt Specific Gravity (G_b)
  - Temperature Viscosity Curve
  - Suggested Mixing and Compaction Temperatures (sometimes)

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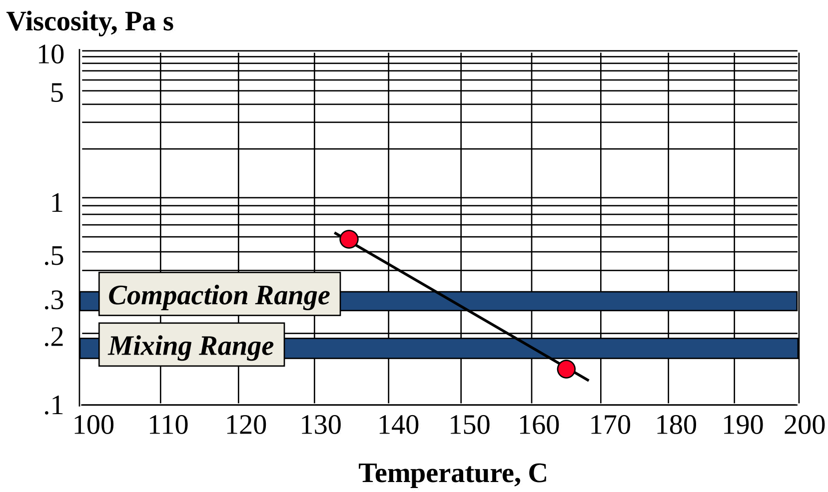
Temperature-Viscosity Curve



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Aggregate

- Sources to be used, plant to be run out of
- Sizes available, quantity
- Stockpile gradations
- RAP does not count as an aggregate!
- Aggregate source properties
  - Fractured face count, glassy particle determination
  - Specific Gravity (individual stockpile)
  - Soundness, L.A. Abrasion

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Aggregate

- Depending on what type mix you are building, you may be restricted on how much of a certain type material you can use in that mix.
  - D Mix cannot have any more than 25% natural sand. (TDOT Spec 411.03)
- Again, RAP does not count as an aggregate!
- Surface mixtures have lower allowable percentages of RAP for durability concerns.

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First Steps

- Blend stockpile gradations mathematically to meet the specified gradation.
- Check blended aggregate properties.
  - (G_{sb}, G_{sa}, LOI, etc)
- Estimate Optimum Asphalt Content from TDOT specifications and old designs (if applicable).
- Prepare mix samples at four or more AC contents around the estimated optimum asphalt content.

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Blending Stockpiles

- **P = A*a* + B*b* + C*c* + ….**
  - Where:
    - P = Percent of material passing a given sieve for the blended aggregates A, B, C, …
    - A, B, C, … = Material passing a given sieve for each aggregate A, B, C, …
    - *a, b, c,* … = Proportions of each aggregate to be used in the blend.

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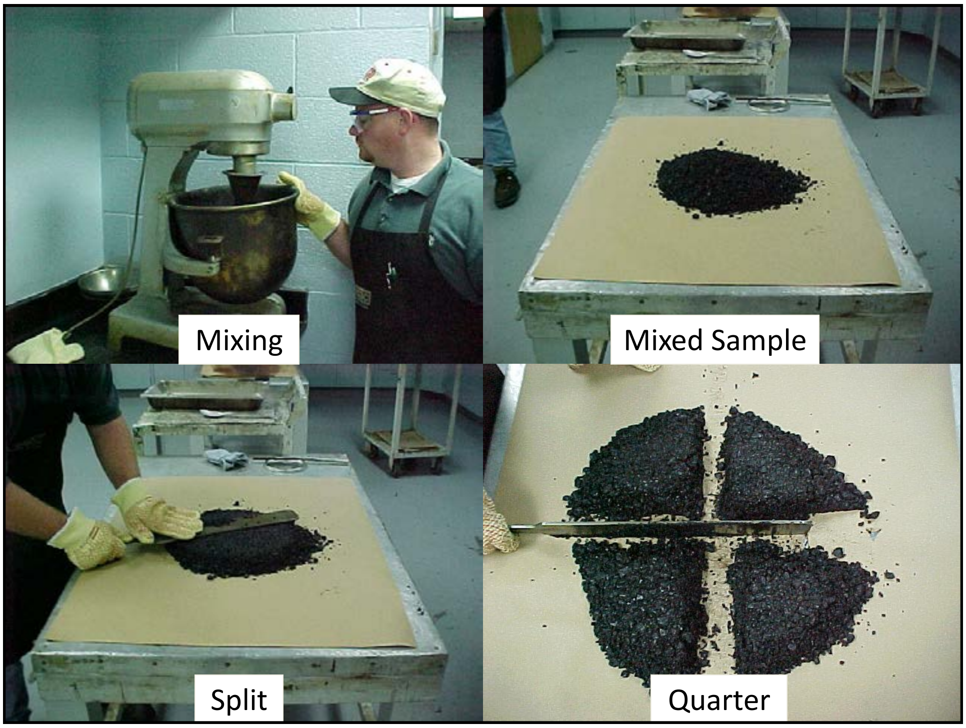
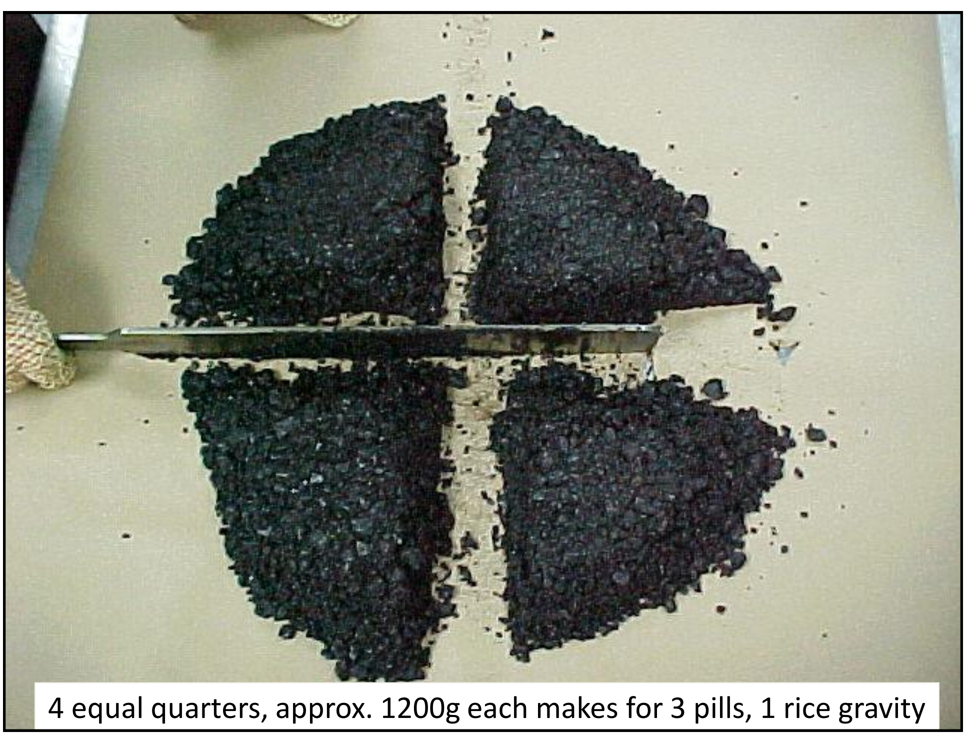



4 equal quarters, approx. 1200g each makes for 3 pills, 1 rice gravity

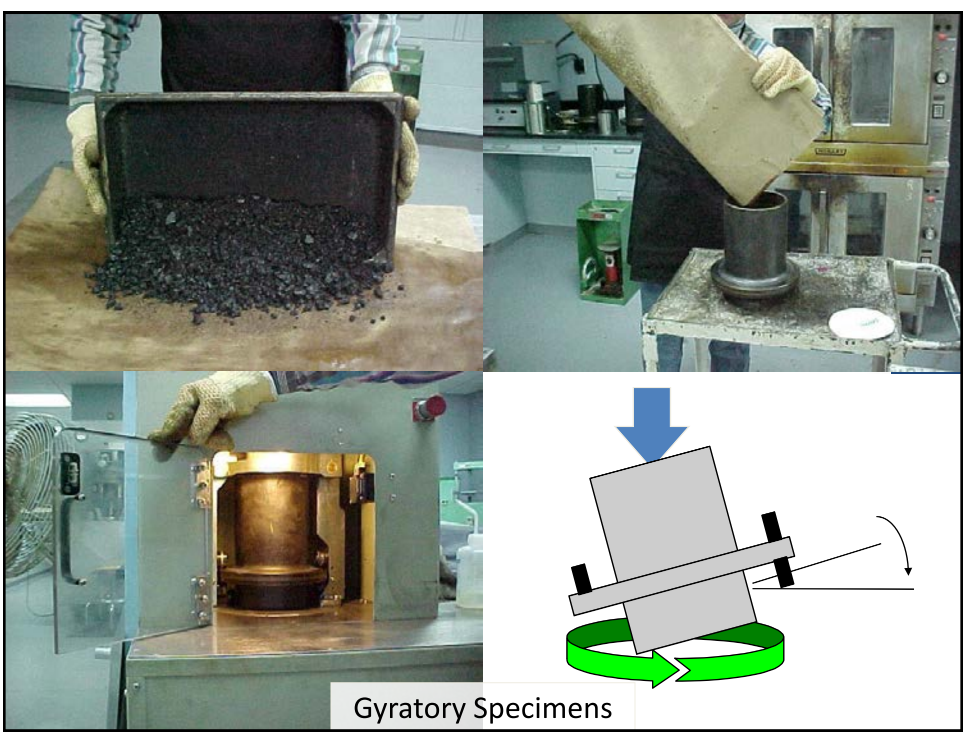
Next Steps

- Age the G_{mm} samples and perform Rice Gravity tests.
  - AASHTO T-209
- Compact the Samples after compaction temperature is reached
  - 75 blows per side: Conventional Mixes
  - N_{design}: Superpave Mixes
- Extrude from the molds
- Allow the samples to cool

AASHTO T-209

- Theoretical Maximum Specific Gravity
- Rice Gravity
- G_{mm}

Marshall Specimens



Gyratory Specimens

Next Steps

- Perform Bulk Gravity tests on samples
  - AASHTO T-166
- Calculate Volumetric Properties:
  - Air Voids in the compacted mix (V_a)
  - Voids in Mineral Aggregate (VMA)
  - Voids Filled with Asphalt (VFA)
- Measure Stability and Flow

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AASHTO T-166

Calculate Volumetric Properties

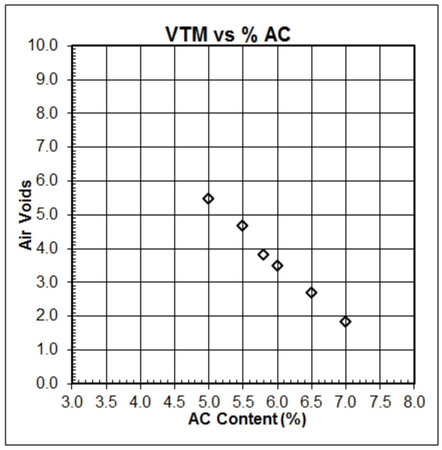
$$VMA_{eff} = 100 - \frac{G_{mb} \times P_s}{G_{se}}$$

$$V_a = 100 \times \frac{G_{mm} - G_{mb}}{G_{mm}}$$

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

AASHTO T-245: Stability/Flow

Plot Data: VTM vs Percent AC



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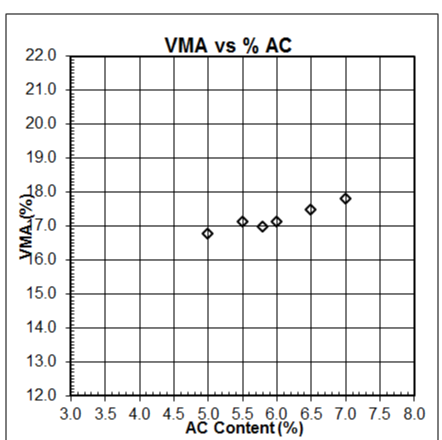
Plot Data: VMA vs Percent AC



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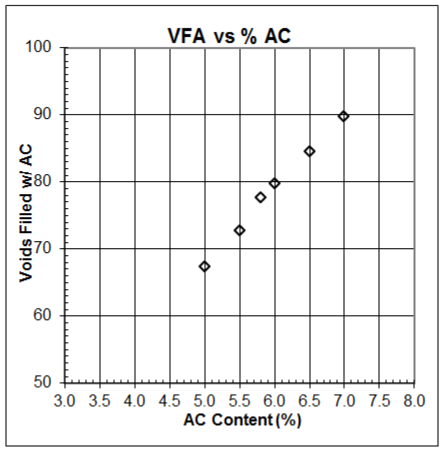
Plot Data: VFA vs Percent AC



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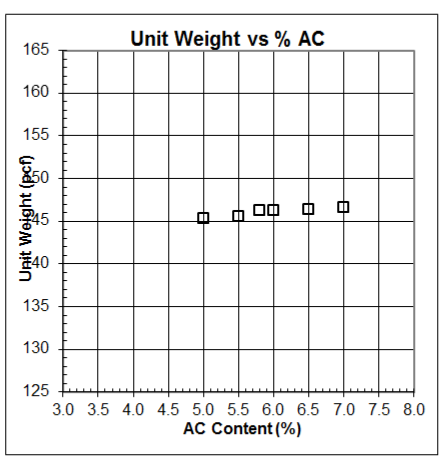
Plot Data: Unit Weight vs Percent AC



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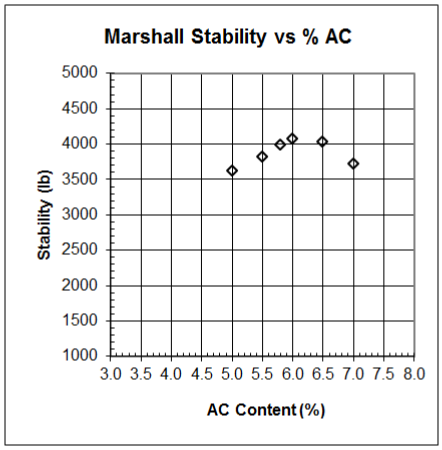
Plot Data: Marshall Stability vs Percent AC



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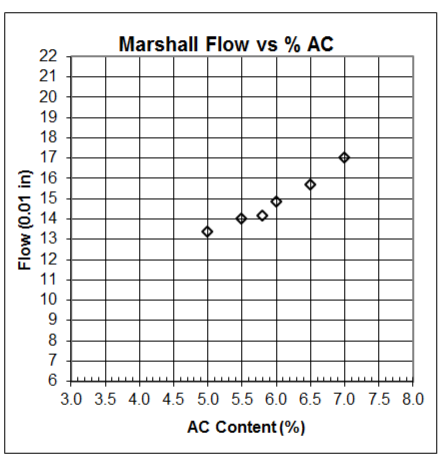
Plot Data: Marshall Flow vs Percent AC



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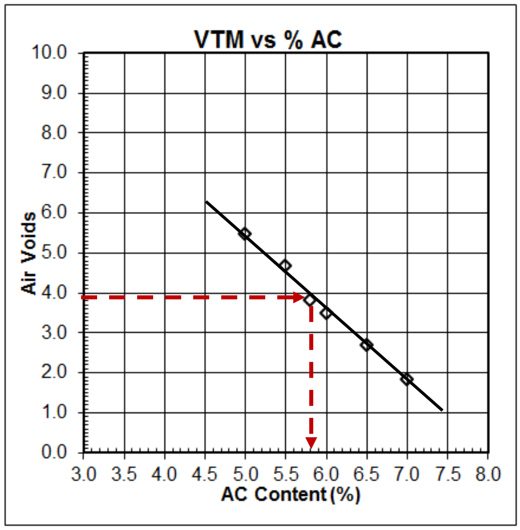
Select Optimum Percent AC



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Check Other Criteria

- Sensitivity of the mixture to asphalt
  - Critical mixture criteria ('Mix Des. Graphs' in JMF Book)
- Specified Stability and Flow (307.03 & 411.03)
- Moisture Sensitivity
  - TSR and Conditioned Tensile Strength (407.03(E))

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Complete Paperwork

- Excel Mix Design File
- Check Design Sheet Information
- Summary Report
- Signature, Cert Number

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4

Aggregates

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Testing Methods for Determining Mix Parameters

Part 1

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AASHTO T-2/ASTM D-75

- Determine NMAS from JMF.
- See TABLE 1 in specification.
  - Determine sample size.

Aggregate Size[A]	Field Sample Mass, min, kg[B] [lb]
	Fine Aggregate
2.36 mm [No. 8]	10 [22]
4.75 mm [No. 4]	10 [22]
	Coarse Aggregate
9.5 mm [⅜ in.]	10 [22]
12.5 mm [½ in.]	15 [35]
19.0 mm [¾ in.]	25 [55]
25.0 mm [1 in.]	50 [110]
37.5 mm [1½ in.]	75 [165]
50 mm [2 in.]	100 [220]
63 mm [2½ in.]	125 [275]
75 mm [3 in.]	150 [330]
90 mm [3½ in.]	175 [385]

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AASHTO T-2/ASTM D-75

AASHTO recommends obtaining belt samples of aggregates whenever possible.

A belt-shaped template must be used.

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AASHTO T-2/ASTM D-75

Use a scoop to remove the aggregate from the portioned section.

Make sure to sweep the fine aggregate off the belt entirely.

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AASHTO T-2/ASTM D-75

Most raw materials must be sampled from a stockpile.

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AASHTO T-2/ASTM D-75

Use power equipment whenever available.

Ensure that the material is re-blended before the loader takes a sample.

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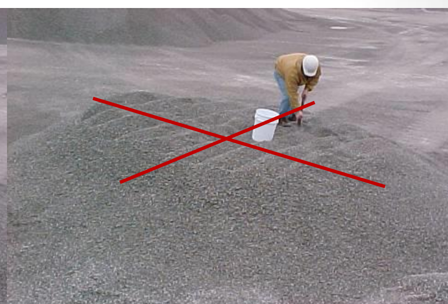
AASHTO T-2/ASTM D-75

Create a small pile adjacent to the original stockpile.

Strike off the top of the pile to create a flat surface.

AASHTO T-2/ASTM D-75



Approach the pile as 4 separate quadrants. Take 1 equal sample from each quadrant.

AASHTO T-2/ASTM D-75

Sample from at Least 3 locations (preferably top, middle, and bottom of the pile).

AASHTO T-2/ASTM D-75

For sampling fine aggregates, a sampling tube may be used.

When using this method, sample in 5 locations.

Aggregate Testing

- Tests to be run:
  - Stockpile Moisture Contents
    - TDOT Method
  - T-27 / T-11 *Washed* Sieve Analysis on ALL aggregates
  - TDOT Glassy Particle Test
    - If **slag** is used as a coarse aggregate.
  - TDOT Fractured Face Count
    - If **gravel** is used as a coarse aggregate.

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AASHTO T-248 Reducing Aggregate Samples for Testing

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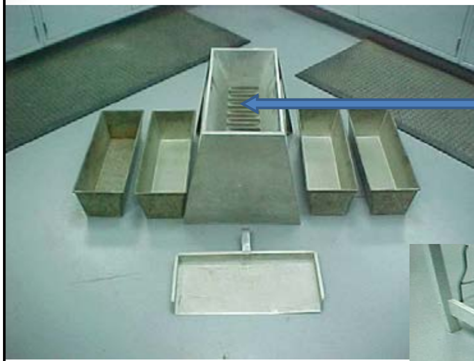
Method A: Mechanical Splitter



Openings may either be fixed or adjustable.

Their widths are dependent upon aggregate size.

Method B: Split and Quarter

1. Start with a small stockpile of material.
2. Flatten the pile to help avoid aggregate roll down.
3. Use a straight edge to cut pile in half.
4. Halve each half with the straight edge for quarters.

AASHTO T-11 Materials Finer Than #200 Sieve in Mineral Aggregate by Washing

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AASHTO T-11

Weigh the oven-dried aggregate and record its mass. Add a bit of wetting agent (mild soap). Be careful not to add too much!

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AASHTO T-11

Add water and stir gently.

Then carefully decant liquid over a nest of sieves.

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AASHTO T-11

Continue washing until the liquid is reasonably clear.

Oven dry the aggregate at 230°F to a constant mass.

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AASHTO T-27
Sieve Analysis of Fine and Coarse Aggregate

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AASHTO T-27

After recording the mass of the oven-dried, washed aggregate, the material must be shaken though a stack of sieves.

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AASHTO T-27

Once the material has been shaken for a sufficient period of time, each sieve must be cleaned out.

The mass of its contents recorded cumulatively.

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AASHTO T-27

AASHTO T-11		
Original Dry Sample Weight (A)	1545.5	grams
Weight Of Sample After Wash, Dried (B)	1474.2	grams
Wash Loss (A-B)	71.3	grams

AASHTO T-27				
US Standard Sieve Sizes	Cumulative Wt. Retained (grams)	Percent Retained (%)	Percent Passing (%)	JMF Design
5/8"	30.3	2.0	98.0	100
1/2"	76.5	4.9	95.1	97
3/8"	287.8	18.6	81.4	85
No.4	615.4	39.8	60.2	58
No.8	858.4	55.5	44.5	46
No.30	1148.5	74.3	25.7	25
No.50	1330.9	86.1	13.9	15
No.100	1420.4	91.9	8.1	10
No.200	1458.1	94.3	5.7	5.3
PAN	1474.2	***	***	***

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Testing Methods for Determining Mix Parameters

Example

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SIEVE ANALYSIS (WASHED)
AASHTO T-11 & AASHTO T-27

Contract No.	Z-000	Contractor	Watts Paving INC.
Project Reference No	STP-99-3(22)	Mix Type	**# 10 (Hard) screenings**

Material Passing #200 Sieve

T-11

ORIGINAL DRY SAMPLE WEIGHT (A)	1500.0	grams
WEIGHT OF SAMPLE AFTER WASH (B)	1331.6	grams
WASH LOSS (A-B)		grams

T-27

PAN WEIGHT (C)		grams
Add'l -#200 Material (C-weight retained #200)		grams
Total Material Passing #200 Sieve		grams

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T-27 RESULTS

U.S. STANDARDS SIEVES	ACCUMULATIVE WEIGHT RETAINED	PERCENT RETAINED	PERCENT PASSING	JMF OR SPECIFICATION
2"				
1 1/2"				
1 1/4"				
1"				
3/4"				
5/8"				
1/2"				
3/8"				
NO. 4	99.9	6.7	$PR = \left(\frac{99.9}{1500.0}\right) \times 100$	
NO. 8	450.9	30.1	$PR = \left(\frac{450.9}{1500.0}\right) \times 100$	
NO. 16				
NO. 30	1040.2	69.3		
NO. 50	1188.2	79.2		
NO. 100	1231.2	82.1		
NO. 200	1290.0	86.0		
Minus #200	1331.6			
TOTAL				

$$Pan = 1331.6 - 1290.0 = 41.6$$

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SIEVE ANALYSIS (WASHED)
AASHTO T-11 & AASHTO T-27

Contract No. Z-000
Project Reference No STP-99-3(22)
Contractor Watts Paving INC.
Mix Type **# 10 (Hard) screenings**

Material Passing #200 Sieve

T-11

ORIGINAL DRY SAMPLE WEIGHT (A)	1500.0	grams
WEIGHT OF SAMPLE AFTER WASH (B)	1331.6	grams
WASH LOSS (A-B)	168.4	grams

T-27

PAN WEIGHT (C)	1331.6	grams
Add'l -#200 Material (C-weight retained #200)		grams
Total Material Passing #200 Sieve		grams

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T-27 RESULTS

U.S. STANDARDS SIEVES	ACCUMULATIVE WEIGHT RETAINED	PERCENT RETAINED	PERCENT PASSING	JMF OR SPECIFICATION
2"				
1 1/2"				
1 1/4"				
1"				
3/4"				
5/8"				
1/2"				
3/8"			100	
NO. 4	99.9	6.7	93.3	$PP = 100 - 6.7$
NO. 8	450.9	30.1	69.9	
NO. 16				
NO. 30	1040.2	69.3	30.7	
NO. 50	1188.2	79.2	20.8	
NO. 100	1231.2	82.1	17.9	
NO. 200	1290.0	86.0	14.0	
Minus #200				
TOTAL	1331.6			

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SIEVE ANALYSIS (WASHED)
AASHTO T-11 & AASHTO T-27

Contract No. Z-000 Contractor Watts Paving INC.
Project Reference No. STP-99-3(22) Mix Type **# 10 (Hard) screenings**

T-27 RESULTS

U.S. STANDARDS SIEVES	ACCUMULATIVE WEIGHT RETAINED	PERCENT RETAINED	PERCENT PASSING	JMF OR SPECIFICATION	
2"					
1 1/2"					
1 1/4"					
1"					
3/4"					
5/8"					
1/2"					
3/8"					
NO. 4	99.9	6.7	93.3		x
NO. 8	450.9	30.1	69.9		x
NO. 16					
NO. 30	1040.2	69.3	30.7		x
NO. 50	1188.2	79.2	20.8		x
NO. 100	1231.2	82.1	17.9		x
NO. 200	1290.0	86.0	14.0		x
Minus #200	1331.6				
TOTAL					

Material Passing #200 Sieve

T-11

ORIGINAL DRY SAMPLE WEIGHT (A)	1500.0	grams
WEIGHT OF SAMPLE AFTER WASH (B)	1331.6	grams
WASH LOSS (A-B)	168.4	grams

T-27

PAN WEIGHT (C)	1331.6	grams
Add'l -#200 Material (C-weight retained #200)	41.6	grams
Total Material Passing #200 Sieve	210.0	grams

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Aggregate Proportioning

(Batching)

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Blending of Aggregates

- Reasons for Blending
  - Obtain desirable gradation
  - Single natural or quarried material not enough
  - Economical to combine natural and processed materials

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Blending of Aggregates

- Numerical Method
  - Trial and Error
  - Basic Formula

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Blending Stockpiles

- **P = A*a* + B*b* + C*c* + ….**
  - Where:
    - P = Percent of material passing a given sieve for the blended aggregates A, B, C, …
    - A, B, C, … = Material passing a given sieve for each aggregate A, B, C, …
    - *a, b, c,* … = Proportions of each aggregate to be used in the blend.

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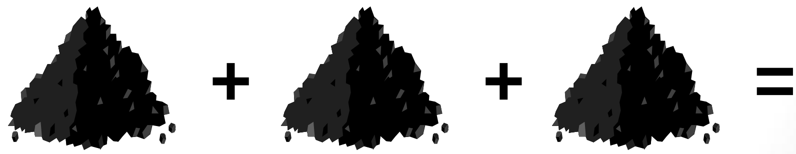
Specific Gravity of Aggregate Blend



Combined Specific Gravity

$$G_{SB} = \frac{(P_A + P_B + P_C)}{\left[\frac{P_A}{G_A} + \frac{P_B}{G_B} + \frac{P_C}{G_C}\right]}$$

Where:
P_A, P_B, & P_C = Percent by mass of each aggregate in blend
G_A, G_B, & G_C = Bulk Specific Gravity of each aggregate

Combined Specific Gravity

$$G_{SB} = \frac{(P_A + P_B + P_C)}{\left[\frac{P_A}{G_A} + \frac{P_B}{G_B} + \frac{P_C}{G_C}\right]}$$

Where:

P_A, P_B, & P_C = Percent by mass of each aggregate in blend

G_A, G_B, & G_C = Bulk Specific Gravity of each aggregate

Based on the information given:

P_A = 50% **G_A = 2.695**

P_B = 25% **G_B = 2.711**

P_C = 25% **G_C = 2.721**

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Combined Specific Gravity

$$G_{SB} = \frac{(P_A + P_B + P_C)}{\left[\frac{P_A}{G_A} + \frac{P_B}{G_B} + \frac{P_C}{G_C}\right]}$$

Where:

P_A, P_B, & P_C = Percent by mass of each aggregate in blend

G_A, G_B, & G_C = Bulk Specific Gravity of each aggregate

Based on the information given:

P_A = 40% **G_A = 2.695**

P_B = 30% **G_B = 2.809**

P_C = 30% **G_C = 2.375**

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Batching Aggregate Blends

Once aggregate proportions have been determined through the sieve analysis, the shaken rock can be recombined into the designed mixture.

Best practice for this method is to add each aggregate and size into individual piles in the event excess must be removed.

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Batching Aggregate Blends

- Why Batch?
  - We Want To Reproduce the Desired Gradation for Mix Design
  - We cannot fire the plant up to make 10 lbs.

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Batching Aggregate Blends

- Things We Must Know To Batch
  - Percent of Each Stockpile in Blend.
  - Percent Retained For Each Sieve of Each Stockpile in the Blend.
- Confidence in gradations is paramount
  - Run at least three per aggregate type.
    - Average the sieve totals from each run.
  - Include quality control numbers from the manufacturer if possible.

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Batching Aggregate Blends

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Batching Aggregate Blends

Batching Aggregate Blends

$$\text{Mass for Batch per Sieve} = \text{Retained per Sieve (Decimal)} \times \text{Percent of Stockpile} \times \text{Batch Wt.}$$

Example: How much #4 material do I need from Aggregate #1 for a 4,000 gram batch?

Given: Percent Retained on #4 sieve = 23.0 %
Percent Agg. #1 Used in Blend = 30.0 %
Total Batch wt. = 4000 grams

Mass of #4 material

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Batching Aggregate Blends

Mass for Batch per Sieve	=	Retained per Sieve (Decimal)	x	Percent of Stockpile	x	Batch Wt.

Example: How much #4 material do I need from Aggregate #1 for a 4,000 gram batch?

Given: Percent Retained on #4 sieve = 23.0 %
Percent Agg. #1 Used in Blend = 30.0 %
Total Batch wt. = 4000 grams

Mass of #4 material = 0.23 x 0.30 x 4000

= 276.0 grams

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Follow the Recipe

Recycled Asphalt Mix

Asphalt Concrete

Existing Pavement

Reclaimed Asphalt Pavement Materials

Milled Aggregates

Salvaged Bitumen

Asphalt Mixture with RAP included

Rap Material + New Aggregate + Virgin AC

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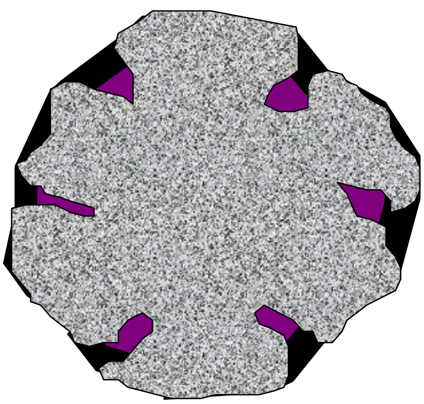
Recycled Asphalt Pavement



Combination of Aged Asphalt and Aggregate

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Preparing to Use RAP

- Shown to be consistent
  - At least 5 samples
  - Consistent binder content
  - Consistent Gradation
- Known location

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Abbreviations

- M_{RAP}= Mass of RAP Material
- P_{RAP}= Decimal Percentage of RAP in Mix
- M_{TOT}= Total Mass of Aggregates in Mix
- $P_{b\ RAP}$= Percent AC in RAP
- $M_{AC\ Pb}$= Mass of Virgin AC

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Rap Blending Calculations

$$M_{RAP} = \frac{P_{RAP} \times M_{Tot}}{(100 - Pb(RAP))}$$

Adding Liquid Asphalt to HMA Mixtures for Known Binder Content

$$M_{ACPb} = \frac{M_{Tot}}{\left(\frac{100 - P_b}{100}\right)} - \frac{M_{RAP} \times P_{bRAP}}{100} - M_{Tot}$$

Total Blend Weight after AC added (asphalt and aggregate)

Subtract RAP's AC Contribution

Agg. Wt.

AC Blending Problem 1

- $M_{(tot)}$ = 4,400 grams
- $P_{(b)}$ = 4.5%
- $P_{(RAP)}$ = 10%
- $P_{b(RAP)}$ = 6.0%

- Calculate Mass of Virgin Binder, $M_{(acpb)}$

Calculate Mass of RAP to Add

$$M_{Rap} = \frac{10 \times 4400}{(100 - 6)} =$$

Calculate amount of AC to Add

$$M_{ACPb} = \frac{4400}{\left(\frac{100-4.5}{100}\right)} - \frac{468.1 \times 6}{100} - 4400$$

$$=$$

$$=$$

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Aggregate Blending Example

Material	# 67	78 - M	W. Scrg	RAP	Blend
Percent	10%	45%	35%	10%	100%
1 inch	100	100	100	100	
3/4 inch	97	100	100	100	
1/2 inch	48	100	100	100	
3/8 inch	22	80	100	100	
No. 4	6	21	94	88	
No. 8	4	5	70	67	
Minus 8					
Batch Weight = 4400 grams			RAP AC =	6%	

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Aggregate Proportioning/Batching

Example

1	2	3	4	5	6
	D Rock(Limestone)		#10 (Soft)	Natural Sand	RAP
	Medium Coarse Aggr		Screenings	Natural Sand	Minus 1/2 inch Rap
	RGI, Lawrenceburg Plant		RGI, Lawrenceburg Plant	Gibbs Construction, Crump, TN	RGI, Lawrenceburg Plant
2"	100.0		100.0	100.0	100.0
1.5"	100.0		100.0	100.0	100.0
1.25"	100.0		100.0	100.0	100.0
1"	100.0		100.0	100.0	100.0
3/4"	100.0		100.0	100.0	100.0
5/8"	100.0		100.0	100.0	100.0
1/2"	95.0		100.0	100.0	100.0
3/8"	72.0		100.0	100.0	94.0
No.4	16.0		100.0	97.0	74.0
No.8	6.0		93.0	82.0	52.0
No.16					
No.30	3.0		70.0	67.0	30.0
No.50	2.0		31.0	14.0	24.0
No.100	1.5		21.0	3.0	17.0
No.200	1.0		18.0	1.0	12.0
			14.0		5.7

903.06 (Base and Binder Mixtures)
903.11 (Surface Mixtures)

Sieve	Percents Used								
	D Rock Limestone	#10 (Soft)	Natural Sand				RAP	% Req.	Design Range
A	50%	10%	25%				15%	100.0	
2"									
1.5"									
1.25"									
1"	B							C	
3/4"									
5/8"	100.0	100.0	100.0				100.0	100.0	100
1/2"	95.0	100.0	100.0				100.0	98.0	95-100
3/8"	72.0	100.0	100.0				94.0	85.0	80-93
No.4	16.0	93.0	97.0				74.0	53.0	54-76
No.8	6.0	70.0	82.0				52.0	38.0	35-57
No.16									
No.30	3.0	31.0	67.0				30.0	26.0	17-29
No.50	2.0	21.0	14.0				24.0	10.0	10-18
No.100	1.5	18.0	3.0				17.0	5.9	3-10
No.200	1.0	14.0	1.0				12.0	4.0	0-6.5

$$\left(\frac{A\times B}{100}\right)+\left(\frac{A\times B}{100}\right)+\left(\frac{A\times B}{100}\right) + \quad + \left(\frac{A\times B}{100}\right) = C$$

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Worksheet for Determining the Aggregate Quantities and their
Corresponding sized fractions for an Aggregate Blend

Mix Type 411-D w/ RAP PG 64-22
Blend Name
Contract No. Z-000

Wt. Total Aggregate Blend **A** 1500 grams

Aggregate	**B** % Used	**C** Wt. (gms)
1) D Rock(Limestone)	50	750
2) #10 (Soft)	10	150
3) Natural Sand	25	375
4)		
5)		
6)		
7) RAP	15	

D

	Sized Fractions	% Passing	Ind. % Retained	Ind wt. Retained	Accum. wt.
	1.5"/1.25"				
	1"	100.0			
	3/4"	100.0			
1)	1/2"	95.0	5	37.5	37.5
	3/8"	72.0	23	172.5	210.0
	#4	16.0	56	420.0	630.0
	#8	6.0	10	75.0	705.0
	-#8		6	45.0	750.0
				750	
	1.5"/1.25"				
	1"				
	3/4"				
	1/2"				
2)	3/8"	100.0			
	#4	93.0	7.0	10.5	760.5
	#8	70.0	23.0	34.5	795.0
	-#8		70.0	105.0	900.0
				150	

Sized Fractions	% Passing	Ind. % Retained	Ind wt. Retained		Accum. wt.
1/2"	100.0				
3/8"	94.0	6.0	14.3		1289.3
7) #4	74.0	20.0	47.7		1337.0
#8	52.0	22.0	52.5		1389.5
-#8		52.0	124.1	239	1513.6

Desired AC Content	Binder Weight
4.00	48.9
4.50	57.1
5.00	65.3
5.50	73.7
6.00	82.1
5.90	80.4

$$M_{ACPb} = \frac{M_{Tot}}{\frac{100 - P_b}{100}} - \frac{M_{RAP} * P_{bRAP}}{100} - M_{Tot}$$

M_{Tot}	1500 g
P_{Rap}	15%
P_{bRap}	5.7%
P_b	5.9%

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Testing Methods for Determining Mix Parameters

Part 2

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AASHTO T-84: Fine Aggregate

Sieve blended aggregates through the #4 sieve.

Use material passing the #4 sieve for this test method.

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AASHTO T-84

Place the material passing the #4 sieve in a pan.

Cover material completely with water.

AASHTO T-84

Allow the fine aggregate to soak for 15 to 19 hours.

Decant the water after soaking.

AASHTO T-84

Partially dry under gently moving warm air while stirring frequently. Do not oven dry.

Cone test of 25 tamps from 5mm/0.2” drop. Continue until saturated surface dry (SSD).

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AASHTO T-84

Initial cone test should stand. Over dried material will fall apart. For SSD, only a small section will fall off.

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AASHTO T-84

- Fill pycnometer with 500 +/- 10 grams of SSD aggregate.
- Fill pycnometer to 90% with deionized water.
- Agitate to remove entrapped air from aggregate.
- Fill to calibration line and remove air bubbles.

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AASHTO T-84

- Alcohol may be used to assist in removal of foam.
- Record the final mass of the pycnometer, aggregate, and water.

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AASHTO T-84

Remove aggregate from flask, dry to a constant mass, and record the dry mass.

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AASHTO T-85: Coarse Aggregate

Sieve blended aggregates through the #4 sieve.

Use material retained on the #4 sieve for this test method.

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AASHTO T-85

Wash the material retained on the #4 sieve and place it in a pan.

Cover material completely with water and let it soak for 15 to 19 hours.

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AASHTO T-85

Decant the water after soaking.

Empty aggregate onto a clean, dry towel.

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AASHTO T-85

Towel dry aggregate to remove the wet sheen from the outer surface (SSD condition).

Record the mass of the SSD material.

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AASHTO T-85

Place all of the material into the basket and place the basket into the water bath.

Shake the submerged basket a few times, let the basket hang awhile, and record the mass.

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AASHTO T-85

Remove aggregate from basket and place into a pan. Be sure to remove all aggregate.

Oven dry to a constant mass.

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TDOT Test for Loss On Ignition (LOI)

Detailed in TDOT Specifications 407.03 (E)

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Loss On Ignition (L.O.I.)

- Performed on 411 D, 411 S, 411 SGC, 411 SMA
- Performed IAW TDOT Spec. 407.03.E
- Results Compared to Value Listed on JMF
- L.O.I. IS A PAY FACTOR

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Test for Percent Loss On Ignition of the Mineral Aggregate in an Asphalt Paving Mixture

Obtain a representative aggregate sample and weigh approximately **600** grams into an assayer's fire clay crucible which has been ignited to constant weight. The crucible must have a cover to prevent pop-out of aggregate while heating. The covered crucible and its contents is then ignited in a muffle furnace at 1742° F **(950° C)** to constant weight (minimum of **8 hours**). The crucible and contents are cooled to room temperature and weighed.

If the aggregate sample has been obtained by extraction with a vacuum extractor, the weights before and after ignition must be corrected for filter aid.

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L.O.I

Record the mass of each container while empty, then fill them with the aggregate.

Record the mass of all of the containers filled with the aggregate.

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L.O.I

Place lids on all of the containers and insert them into the furnace.

Place a piece of ceramic media on top of the lids to hold them in place.

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L.O.I

Minimum burn time is 8 hours.

Record the mass of all of the containers filled with the ignited aggregates.

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L. O. I.
(Calculations)

1 Determining Weight of Sample

Note : Minimum Sample Size = 600 Grams

(A)	Weight of Agg. From Burnout Oven		**900.0**
	Weight of Sample Container (Crucible)	+	**1100.0**
	Total Wt. Of Agg. + Sample Container	=	

2 Determining Weight Loss

Wt. of Container + Test Sample (Before Ignition)	
Wt. of Container + Test Sample (After Ignition)	
(B) Weight Loss	

3 Calculating L.O.I. :

L.O.I. = (B) Divided by (A) x 100

Inspector Farley Pinwheel

Title Pannido I

Remarks : No Filter Aid Used . Sample taken from Burnout oven

Form found in workbook.

Now we need to calculate our L.O.I. pay factor.

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Glassy Particles Test

When slag is used as a coarse aggregate a check for glassy particles must be performed.

A sample of material retained on the #4 sieve cannot exceed 20% glassy particles by mass.

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Glassy Particles (Slag)
Subsection 903.11(a)(4)

Does mix contain slag used as coarse aggregate Yes ☒
No ○

Crushed slag coarse aggregate shall contain no more than 20%, by weight, of glassy particles; except that where used in Grading G mix, the percent of glassy particles, by weight, shall not exceed 10%.
A representative sample containing at least 300 grams of the (+4) slag should be used.*
* DOT Policy

$$\% \text{ Glassy Particles} = \frac{\text{Mass of Glassy Particles}}{\text{Total Mass of Sample Used}} \times 100\%$$

Mass of Glassy Particles ________ g
Total Mass of Sample Used ________ g

% Glassy Particles = ________ %

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Fractured Face Count

When gravel is used as a coarse aggregate some of the material is crushed. Some material will not fracture during this process.

Percentage of particles with two or more fractured faces should be determined by count.

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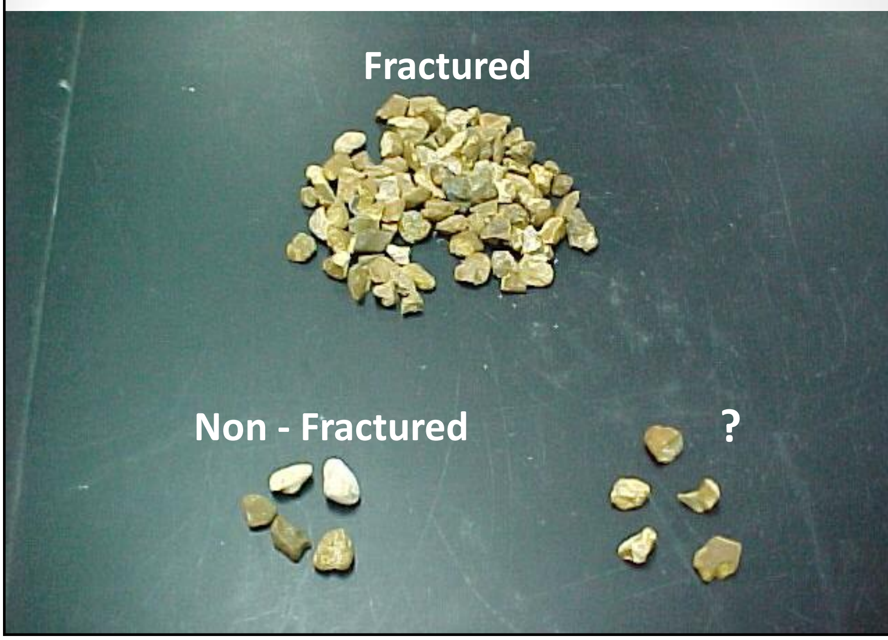
Fractured Face Count



Fractured Face Count
Subsection 903.11(a)(3)

Is Crushed Gravel used as a coarse aggregate in this mix? Yes ☒ No ●

At least 70% by count, of the material retained on the 4.75 mm (No. 4) sieve shall have a minimum of two fractured faces, one of which must be fractured for the approximate average diameter or thickness of the particle. A representative sample containing at least 200 grams should be used.

$$\% \text{ Fractured} = \frac{\text{No. of Particles Fractured}}{\text{Total No. of Particles Inspected}}$$

No. of Particles Fractured ________

Total No. of Particles Inspected ________

% Fractured = ________

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ASTM D-4791

Flat and Elongated Particles

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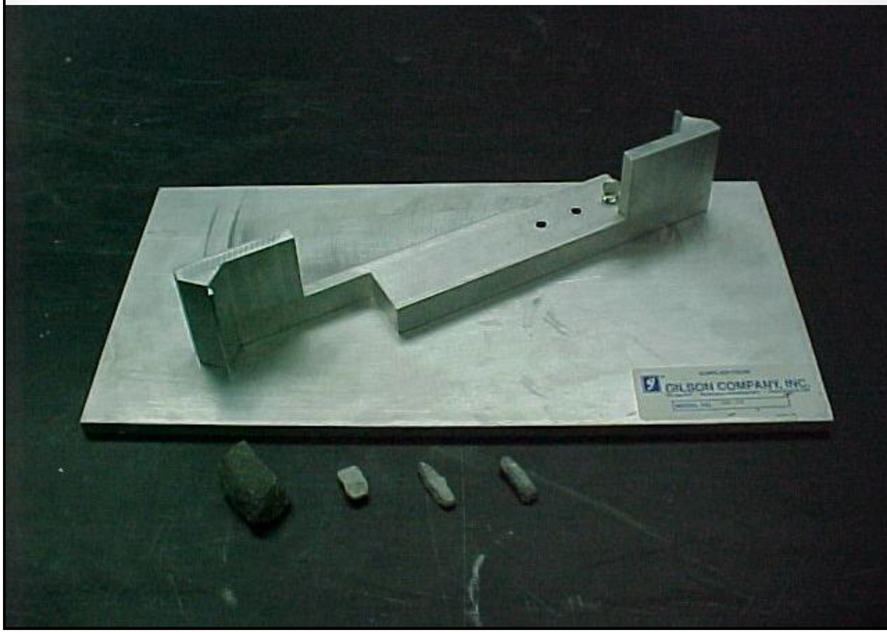
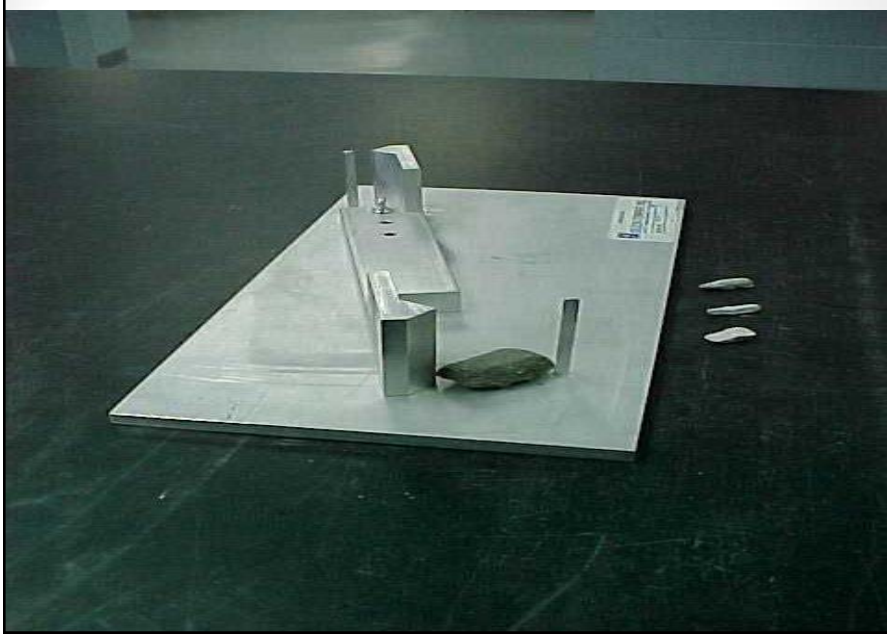
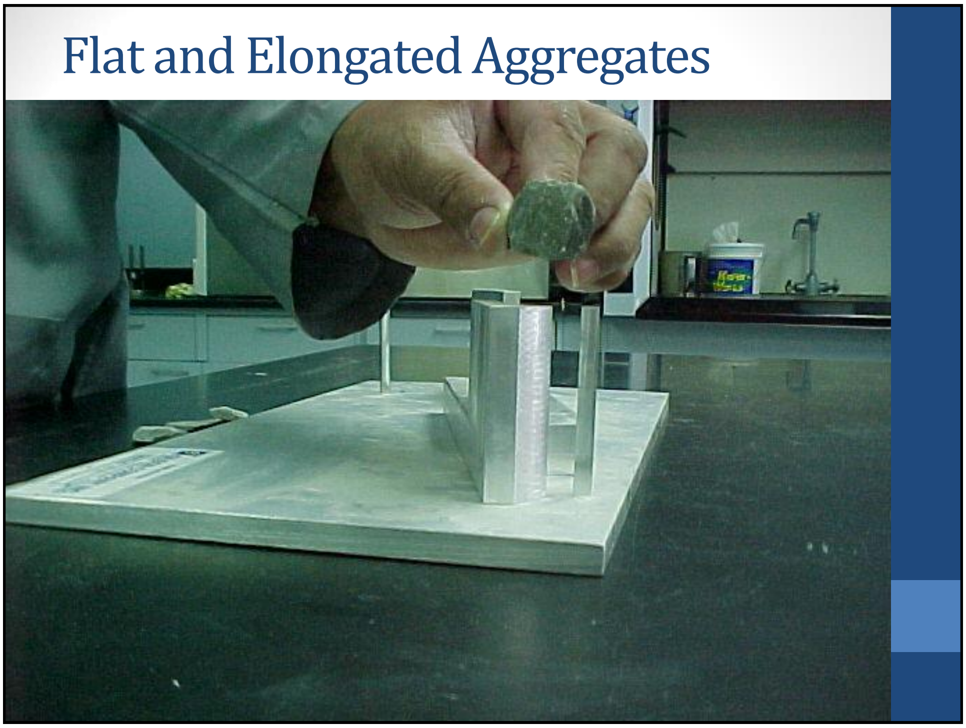
Flat and Elongated Aggregates



Flat and Elongated Aggregates




Flat and Elongated Aggregates

Testing Methods for Determining Mix Parameters

Part 2: Example

Specific Gravity and Absorption of Aggregates
AASHTO T-84 AND T-85
Blended Aggregates

From the Job Mix Formula:

% Passing #4 Sieve	58.4
% Retained on #4 Sieve	41.6

Fine Aggregate: (-4 Matl.) AASHTO T-84

A--Mass of Oven Dried Sample	500.0	grams
B--Mass of Flask and Water	1000.0	grams
C--Mass of Flask and Water and Sample	1300.0	grams
D--Mass of Saturated Surface Dried Sample	504.0	grams

$$\text{Bulk Specific Gravity} = \frac{A}{B + D - C} =$$

$$\text{Apparent Specific Gravity} = \frac{A}{B + A - C} =$$

Coarse Aggregate: (+4 Matl.) AASHTO T-85

A--Mass of Oven Dried Sample	1500.0	grams
B--Mass of Saturated Surface Dried Sample	1515.0	grams
C--Mass of Sample in Water	995.0	grams

2.885

2.970

Combined Specific Gravity

$$\frac{100}{\frac{\%\ F.\ A.}{Sp.\ Gr.\ F.A.} + \frac{\%\ C.\ A.}{Sp.\ Gr.\ C.A.}}$$

Combined Bulk Specific Gravity (Gsb)	2.614
Combined Apparent Specific Gravity (Gsa)	2.676
Combined Blend Absorption	.9

Combined Absorption

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Loss on Ignition (L. O. I.)
T. D. O. T. Procedures

		(1)	(2)	(3)	(4)	
Mass Crucible & Test Sample (before ignition)		1908.1				g
Mass Crucible	(-)	427.3				g
Mass Test Sample		1480.8				g
Mass Crucible & Test Sample (before ignition)		1908.1				g
Mass Crucible & Test Sample (after ignition)		1585.0				g
Mass Loss		323.1 g	g	g	g	

Combined Masses from above:

Mass of Test Samples	1480.8 g
Mass of Losses	323.1 g

$$\%\ \text{Loss on Ignition (L. O. I.)} = \frac{\text{Mass of Losses}}{\text{Mass of Test Samples}} \times 100$$

% L. O. I. 21.8

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Fractured Face Count
Subsection 903.11(a)(3)

Is Crushed Gravel used as a coarse aggregate in this mix? Yes ◉ No ○

At least 70% by count, of the material retained on the 4.75 mm (No. 4) sieve shall have a minimum of two fractured faces, one of which must be fractured for the approximate average diameter or thickness of the particle.

A representative sample containing at least 200 grams should be used.

$$\% \text{ Fractured} = \frac{\text{No. of Particles Fractured}}{\text{Total No. of Particles Inspected}} \text{ X } 100$$

No. of Particles Fractured 285
Total No. of Particles Inspected 345

% Fractured = 82.6 %

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Glassy Particles (Slag)
Subsection 903.11(a)(4)

Does mix contain slag used as coarse aggregate? Yes ◉ No ○

Crushed slag coarse aggregate shall contain no more than 20%, by weight, of glassy particles; except that where used in Grading G mix, the percent of glassy particles, by weight, shall not exceed 10%.

A representative sample containing at least 300 grams of the (+4) slag should be used.*

* DOT Policy

$$\% \text{ Glassy Particles} = \frac{\text{Mass of Glassy Particles}}{\text{Total Mass of Sample Used}} \times 100\%$$

Mass of Glassy Particles 36.3 g
Total Mass of Sample Used 426.9 g

% Glassy Particles = 8.5 %

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0.45 Power Charts

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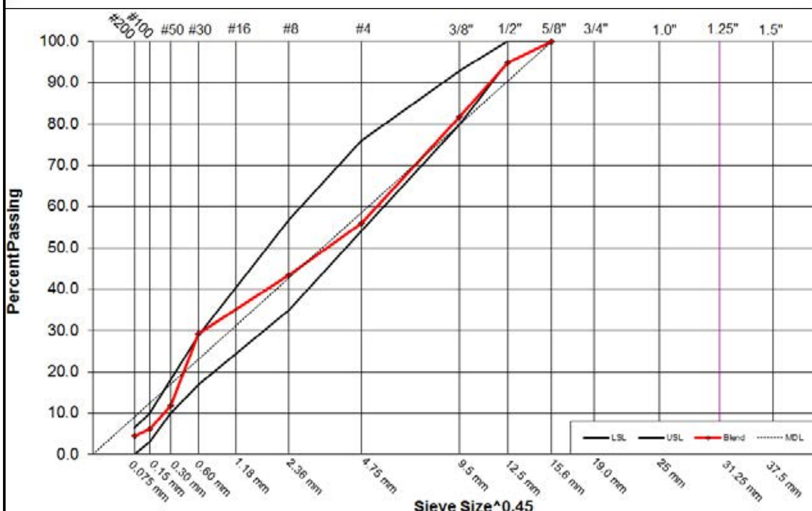
0.45 Power Charts



Sieve (in)	% Pass
2"	
1.5"	
1.25"	
1"	
3/4"	
5/8"	100
1/2"	95
3/8"	82
No.4	56
No.8	44
No.16	
No.30	29
No.50	12
No.100	6
No.200	5

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0.45 Power Charts

- Provide us with a visual interpretation of our blend of aggregates.
- Helps visually determine whether a blend is going to be coarse, fine, open graded, gap graded, etc.
- Helps evaluate VMA issues.

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Why to the 0.45 Power?

- Years back, it was determined that raising sieve sizes to the 0.45^{th} power more effectively helps us evaluate mixes.

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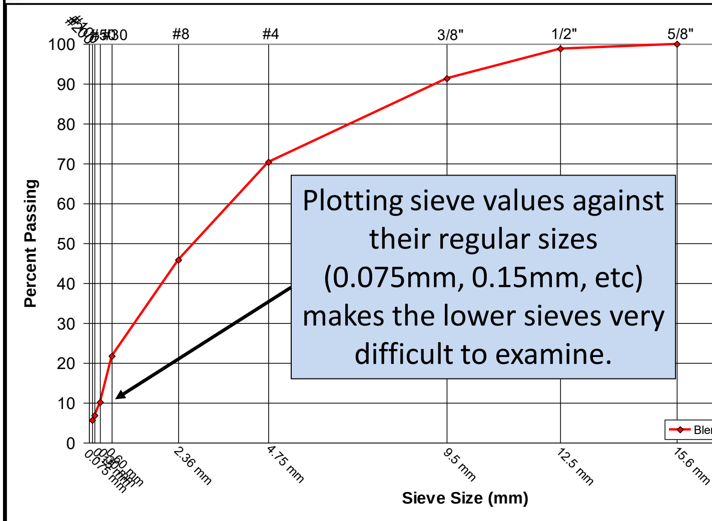
Why to the 0.45 Power?



Sieve (in)	% Pass
1.25"	100
1"	100
3/4"	100
5/8"	100
1/2"	99
3/8"	91
No.4	70
No.8	46
No.16	
No.30	22
No.50	10
No.100	7
No.200	6

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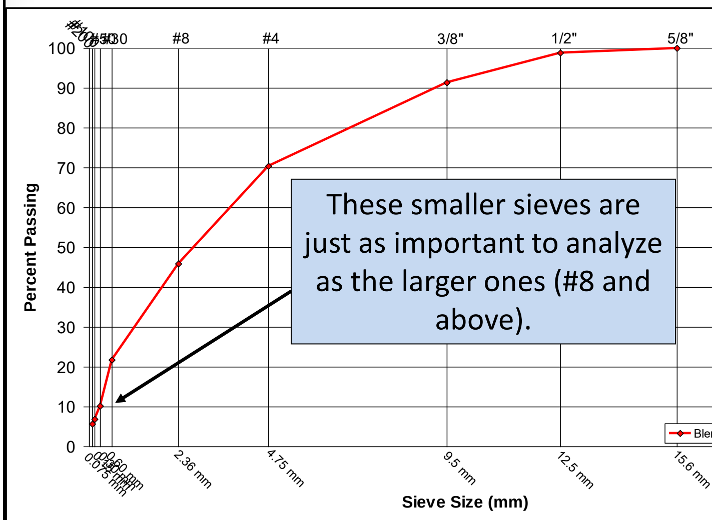
Why to the 0.45 Power?



Sieve (in)	% Pass
1.25"	100
1"	100
3/4"	100
5/8"	100
1/2"	99
3/8"	91
No.4	70
No.8	46
No.16	
No.30	22
No.50	10
No.100	7
No.200	6

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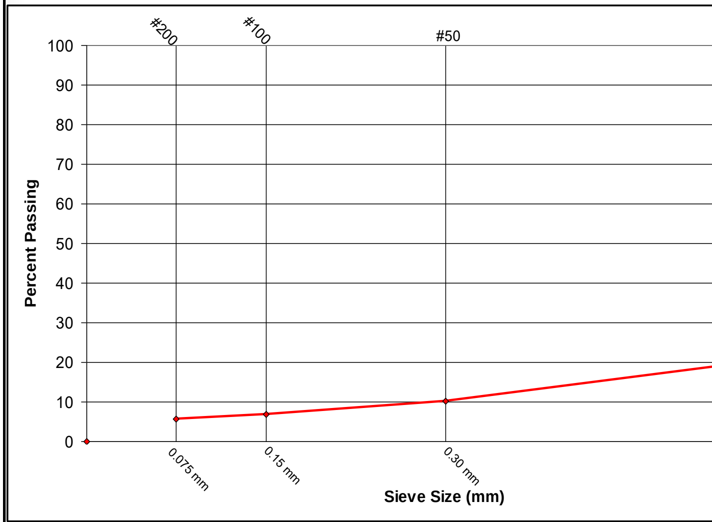
Why to the 0.45 Power?



Sieve (in)	% Pass
1.25"	100
1"	100
3/4"	100
5/8"	100
1/2"	99
3/8"	91
No.4	70
No.8	46
No.16	
No.30	22
No.50	10
No.100	7
No.200	6

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Why to the 0.45 Power?

- Try taking the same blend and raising the sieve values (in millimeters) to the 0.45 power:
  - For example – the #8 sieve (2.36 mm) raised to the 0.45 Power equals:

$$(2.36)^{0.45} = 1.472$$

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Why to the 0.45 Power?

When 0.45 Power is applied to the sieve sizes in millimeters it reduces the range of the numbers corresponding to the sieve sizes. Thus, making the graph of the gradation much easier to analyze.

Sieve (in)	Sieve^0.45	% Pass
1.25"	4.706	100
1"	4.257	100
3/4"	3.762	100
5/8"	3.443	100
1/2"	3.116	99
3/8"	2.754	91
No.4	2.016	70
No.8	1.472	46
No.16	1.077	-
No.30	0.795	22
No.50	0.582	10
No.100	0.426	7
No.200	0.312	6

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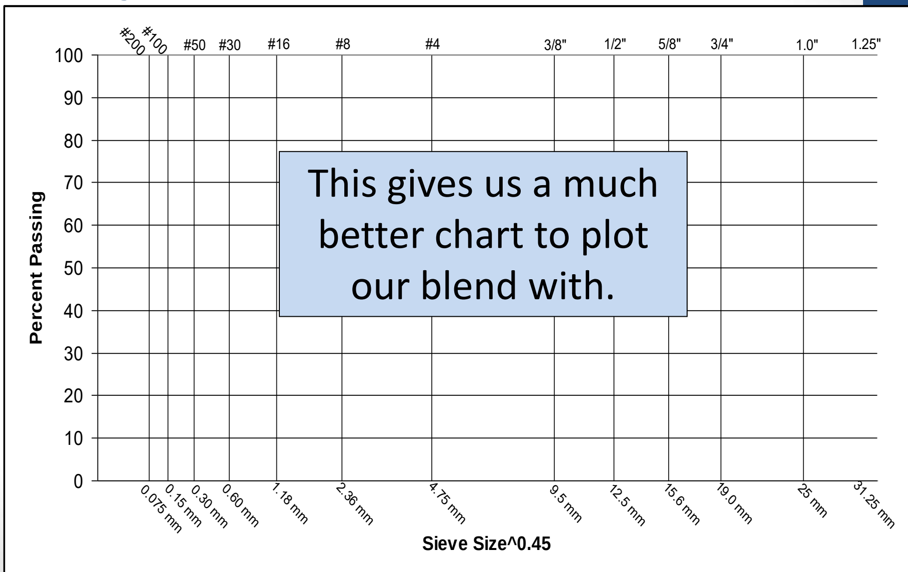
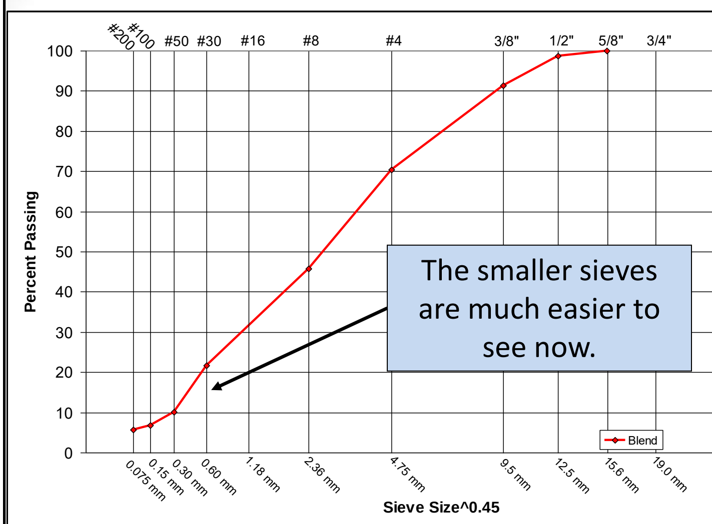
Why to the 0.45 Power?



Why to the 0.45 Power?

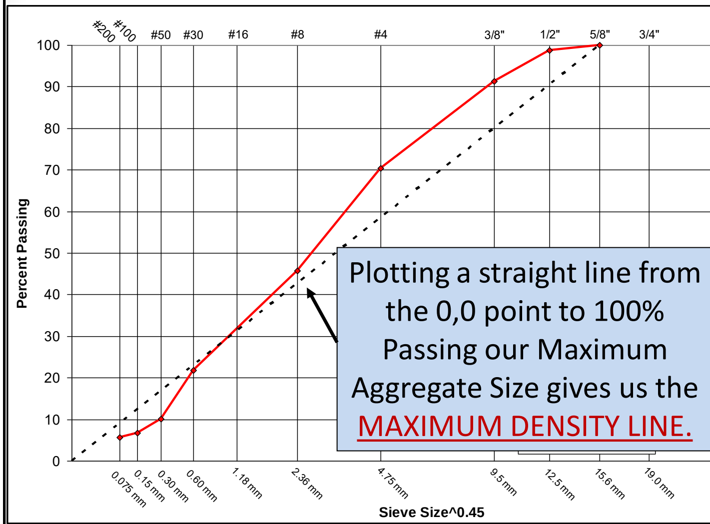
- Now let us plot our percent passing values for a blend against these 0.45 Power numbers.

Why to the 0.45 Power?



Sieve (in)	% Pass
1.25"	100
1"	100
3/4"	100
5/8"	100
1/2"	99
3/8"	91
No.4	70
No.8	46
No.16	
No.30	22
No.50	10
No.100	7
No.200	6

Why to the 0.45 Power?



Sieve (in)	% Pass
1.25"	100
1"	100
3/4"	100
5/8"	100
1/2"	99
3/8"	91
No.4	70
No.8	46
No.16	
No.30	22
No.50	10
No.100	7
No.200	6

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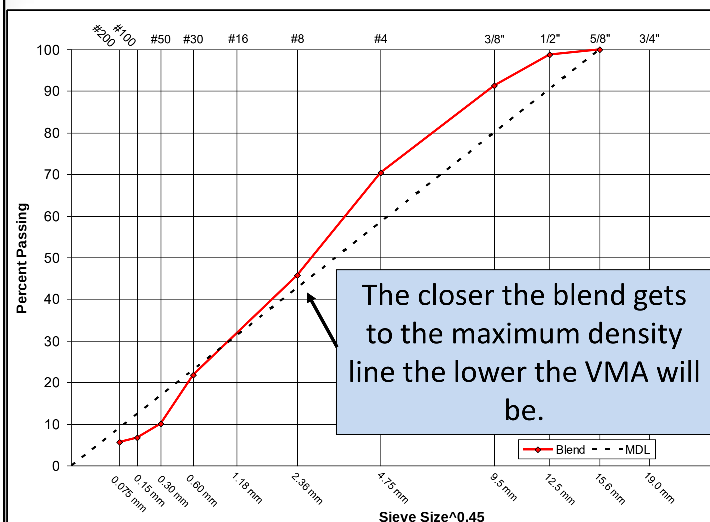
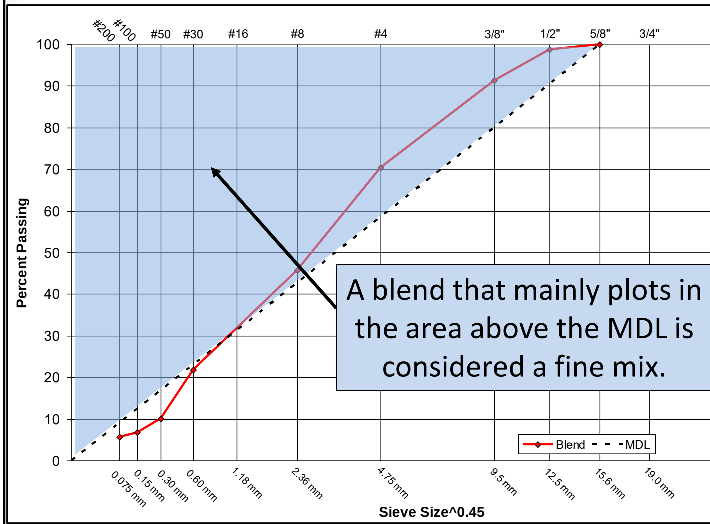
Why to the 0.45 Power?



Sieve (in)	% Pass
1.25"	100
1"	100
3/4"	100
5/8"	100
1/2"	99
3/8"	91
No.4	70
No.8	46
No.16	
No.30	22
No.50	10
No.100	7
No.200	6

TN TDOT Department of Transportation

Why to the 0.45 Power?



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No.16	
No.30	22
No.50	10
No.100	7
No.200	6

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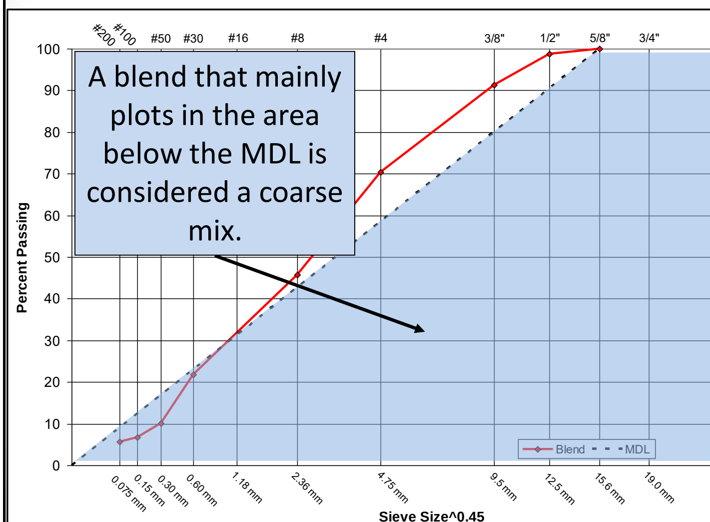
Why to the 0.45 Power?



Sieve (in)	% Pass
1.25"	100
1"	100
3/4"	100
5/8"	100
1/2"	99
3/8"	91
No.4	70
No.8	46
No.16	
No.30	22
No.50	10
No.100	7
No.200	6

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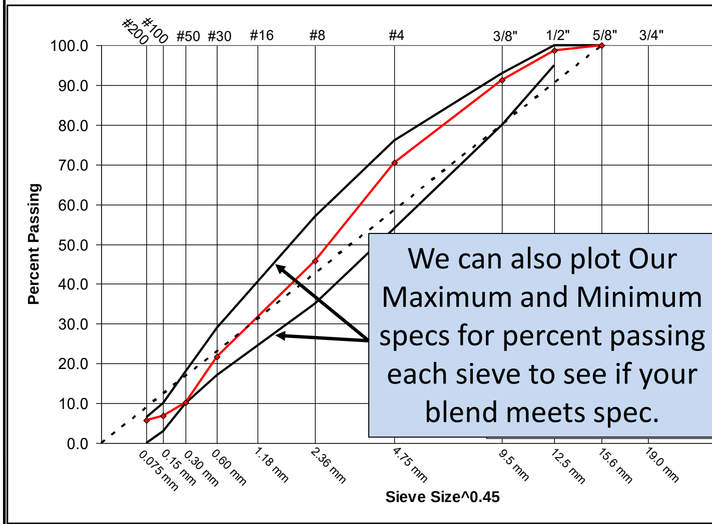
Why to the 0.45 Power?



Sieve (in)	% Pass
1.25"	100
1"	100
3/4"	100
5/8"	100
1/2"	99
3/8"	91
No.4	70
No.8	46
No.16	
No.30	22
No.50	10
No.100	7
No.200	6

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Dust / Asphalt Ratio

- Most TDOT mixes have specification ranges for Dust to Asphalt Ratio (DAR)
- DAR = (%Passing #200 sieve)

  (% Asphalt Content)
- Why is this ratio important?

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Dust / Asphalt Ratio

- For the mix we plotted a minute ago, the percent passing #200 was 6.0%. Say the optimum asphalt content for this design was 5.3%. What is the DAR?

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5

Asphalt Mixtures

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Testing Asphalt Mixtures

Part 1

TN TDOT Department of Transportation

AASHTO T-245

Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus

TN TDOT Department of Transportation

AASHTO T-245

AASHTO T-245

AASHTO T-245

AASHTO T-245

AASHTO T-245

AASHTO T-209

Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures

TN TDOT Department of Transportation

AASHTO T-209

AASHTO T-209

TN TDOT Department of Transportation

AASHTO T-209

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AASHTO T-209

AASHTO T-209

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AASHTO T-209

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AASHTO T-209

Maximum Specific Gravity:

$$G_{mm} = \frac{A}{(A + D - E)}$$

where: A = Mass of dry sample
D = Mass of container filled with water
E = Mass of container filled with sample and water

G_{mm} Example

- Some loose mix weighs 2234.0 g dry.
- The Pycnometer filled with water weighs 7246.3 g.
- The pycnometer filled with water AND sample weighs 8595.7 g.
- Calculate G_{mm} value for this mix:

AASHTO T-166

Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry

TN TDOT Department of Transportation

AASHTO T-166

AASHTO T-166

Bulk Specific Gravity :

$$G_{mb} = \frac{\text{Dry Mass of Specimen}}{(\text{SSD Mass}) - (\text{Submerged Mass})}$$

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G_{mb} Example

- A Marshall pill weighs:
  - 1214.7 g Dry
  - 712.1 g Under Water
  - 1215.9 g After Blotting Dry (SSD)
- Calculate G_{mb} value for this mix:

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Volumetrics

VOLUMETRICS

VOLUMETRICS FLOW CHART FOR MIX DESIGN DATA @ CHOOSEN % ASPHALT CONTENT

MIX DESIGN SHEET

% AC
% AGGREGATE

BULK SPECIFIC GRAVITY
MASS (IN GRAMS)
IN AIR, SSD, IN WATER
VOLUME (ml)

G_{mb}
BULK SPECIFIC GRAVITY OF COMPACTED SPECIMENS
SSD - IN WATER = VOLUME
IN AIR / VOLUME $= G_{mb}$

V_a OR VTA
AIR VOIDS OR VOIDS IN TOTAL COMPACTED MIX
$100 \times G_{mm} - G_{mb} / G_{mm}$

VMA
VOIDS IN MINERAL AGGREGATE OF COMPACTED MIX
$100 - G_{mb} \times P_s / G_{sb} = VMA_{BULK}$
$100 - G_{mb} \times P_s / G_{se} = VMA_{EFFECTIVE}$

VFA
VOIDS FILLED WITH ASPHALT IN COMPACTED MIX
$100 \times VMA_{BULK} - V_a / VMA_{BULK}$
$100 \times VMA_{EFF} - V_a / VMA_{EFF}$

RICE SPECIFIC GRAVITY
AASHTO T- 209
FOR % AC CHOSEN

G_{mm}
AASHTO T- 209
FOR % AC CHOSEN

G_{se}
EFFECTIVE SPECIFIC GRAVITY OF AGGREGATES
$P_{mm} - P_b / (P_{mm} / G_{mm} - P_b / G_b) = G_{se}$

VOLUMETRICS

VOLUMETRICS FLOW CHART FOR MIX DESIGN DATA @ CHOOSEN % ASPHALT CONTENT

MIX DESIGN SHEET

% AC
% AGGREGATE

BULK SPECIFIC GRAVITY
MASS (IN GRAMS)
IN AIR, SSD, IN WATER
VOLUME (ml)

G_{mb}
BULK SPECIFIC GRAVITY OF COMPACTED SPECIMENS
SSD - IN WATER = VOLUME
IN AIR / VOLUME = G_{mb}

V_a OR VTA
AIR VOIDS OR VOIDS IN TOTAL COMPACTED MIX
$100 \times G_{mm} - G_{mb} / G_{mm}$

VMA
VOIDS IN MINERAL AGGREGATE OF COMPACTED MIX
$100 - (G_{mb} \times P_s) / G_{sb} = VMA_{BULK}$
$100 - (G_{mb} \times P_s) / G_{se} = VMA_{EFFECTIVE}$

VFA
VOIDS FILLED WITH ASPHALT IN COMPACTED MIX
$100 \times VMA_{BULK} - V_a / VMA_{BULK}$
$100 \times VMA_{EFF} - V_a / VMA_{EFF}$

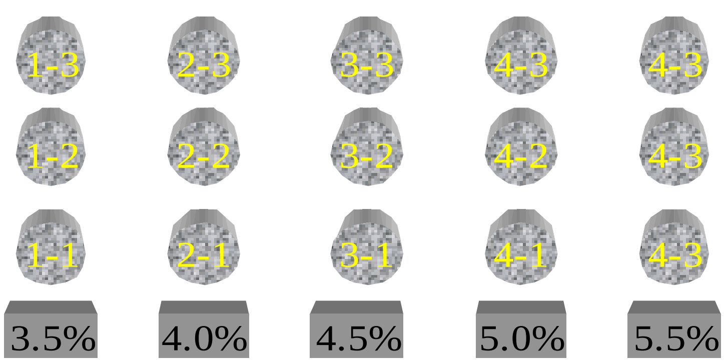
G_{mm} MAXIMUM SPECIFIC GRAVITY OF MIX
RICE GRAVITY @ CHOSEN ASPHALT CONTENT
AASHTO T- 209
FOR % AC CHOSEN

G_{mm}
AASHTO T- 209
FOR % AC CHOSEN

G_{se}
EFFECTIVE SPECIFIC GRAVITY OF AGGREGATES
$P_{mm} - P_b / ((P_{mm} / G_{mm}) - (P_b / G_b)) = G_{se}$

G_{mm}
CALCULATED MAXIMUM SPECIFIC GRAVITY OF MIX
@ DIFFERRENT ASPHALT CONTENTS
Gmm = Pmm / ((Ps / Gse) + (Pb / Gb))

Volumetrics of Compacted Mixture

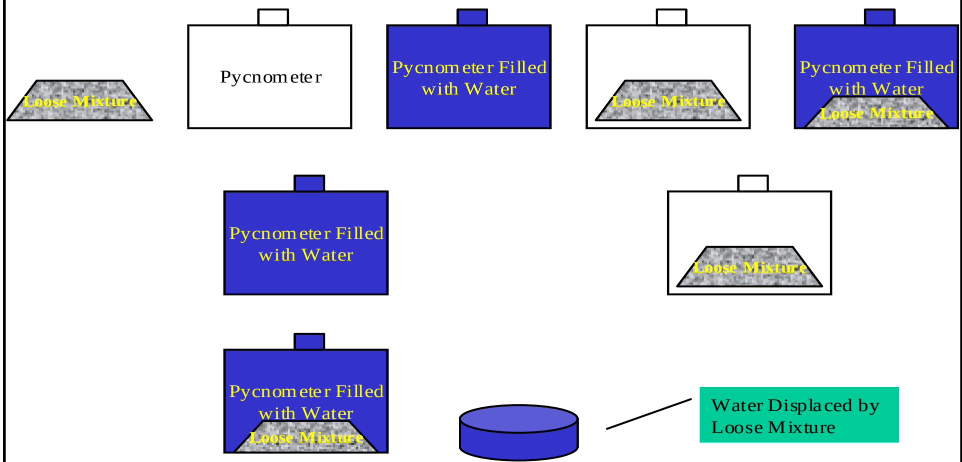


Maximum Specific Gravity of Compacted Mixture

Maximum Specific Gravity of Compacted Mixture

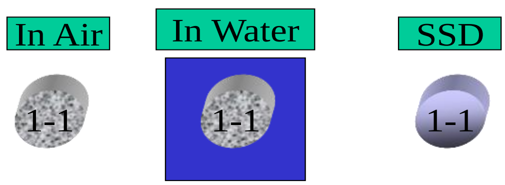
AASHTO T-209 for chosen Asphalt Content

AASHTO T- 209 for chosen Asphalt Content



Bulk Gravity of Compacted Mixture

MASS in Grams



$$\text{Gmb} = \frac{\text{Wt. In Air}}{(\text{SSD Wt.} - \text{Wt. In Water})}$$

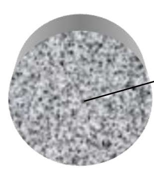
Aggregates

Using Gmm from AASHTO T- 209 (Rice Gravity) for chosen Asphalt C

Gb = Gravity of the Asphalt Cement

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

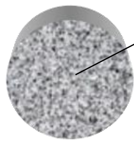
Air Voids or Voids in Compacted M



Voids in Compacted Mix Consist of Small Air Spaces Between the Coated Particles

$$Va = 100 \times \frac{Gmm - Gmb}{Gmm}$$

VMA
Voids in Mineral Aggregate

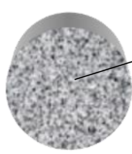


VMA are Defined as the Intergranular Void Space Between the Aggregate Particles in a Compacted Mixture that Includes the Air Voids and the Effective Asphalt Content, Expressed as a Percent of Total Volume

Ps = % of Aggregate by Total Mass of Mixture

$$VMA_{eff} = 100 - \frac{Gmb \times Ps}{Gse}$$

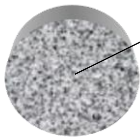
Voids Filled with Asphalt



VFA is Defined as the Percentage of the Voids in the Mineral Aggregate that are filled with Asphalt

$$VFA_{eff} = 100 \times \frac{VMA_{eff} - Va}{VMA_{eff}}$$

Mixture



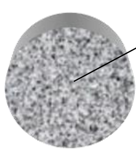
The Effective Asphalt Content of a paving Mixture is the Total Asphalt Content Minus the Quantity of asphalt lost by absorption into the Aggregate Particles

Pb = Percent Asphalt Content

Ps = Percent Aggregate Content

$$Pbe = Pb - \frac{Pba}{100} \times Ps$$

Asphalt Absorption



Absorption is Expressed as a Percentage by Mass of Aggregate rather than as a Percentage of Total Mass of Mixture

$$Pba = 100 \times \frac{Gse - Gsb}{Gsb \times Gse} \times Gb$$

Mix Design Sheet

Mix Des. Data

State of Tennessee Marshall Mix Design Sheet

Type of Mix	307-BM w/ RAP PG 64-22	Contract No.	2002	Contractor	Mix Design
County	Davidson	Date	1/15/2002	Effective Gravity of Aggregate	2.696
Project Ref. No.	2002 School Design	Region	3	SG of Asphalt	1.032

Sample No.	% AC	% Agg.	Mass (grams) In Air	Mass (grams) SSD	Mass (grams) In Water	Volume (ml)	Bulk SG	Rice SG or TMD	VTM (%)	VMA (%)	VFA (%)	Unit Weight (pcf)	Stability (lb)	Flow (0.01")
1-1	3.5	96.5	1195.5	1200.9	704.8	496.1	2.410	2.552	5.8	13.9	58.5	150.0	2550	10.5
1-2			1197.1	1203.1	705.1	498.0	2.404						2340	9.0
1-3			1196.0	1201.8	703.2	498.6	2.399						2680	10.0
						Avg	2.404					Avg	2523	9.8
2-1	4.0	96.0	1199.1	1202.8	706.5	496.3	2.416	2.532	4.4	13.8	68.0	151.0	2565	11.5
2-2			1202.1	1206.3	709.2	497.1	2.418						2910	11.0
2-3			1195.7	1199.0	706.4	492.6	2.427						2515	10.0
						Avg	2.421					Avg	2663	10.8
3-1	4.5	95.5	1195.7	1199.2	708.1	491.1	2.435	2.513	3.1	13.7	77.2	151.9	2390	11.8
3-2			1198.0	1200.0	707.9	492.1	2.434						2925	12.2
3-3			1193.5	1197.2	706.9	490.3	2.434						2875	12.0
						Avg	2.434					Avg	2730	12.0
4-1	5.0	95.0	1196.9	1198.2	709.3	488.9	2.448	2.494	1.9	13.8	86.1	152.7	3025	13.0
4-2			1195.5	1198.3	709.2	489.1	2.444						2975	13.8
4-3			1194.5	1197.5	709.4	488.1	2.447						2925	13.5
						Avg	2.447					Avg	2975	13.4
5-1	5.5	94.5	1197.1	1197.2	708.6	488.6	2.450	2.476	1.0	14.1	92.7	152.9	3050	14.5
5-2			1198.6	1198.8	709.9	488.9	2.452						3150	15.2
5-3			1195.8	1195.9	707.8	488.1	2.450						3175	15.1
						Avg	2.451					Avg	3125	14.9
Opt-1	4.2	95.8	1197.1	1201.9	707.6	494.3	2.422	2.525	3.9	13.7	71.8	151.4	2550	11.5
Opt-2			1198.6	1201.9	708.7	493.2	2.430						2475	11.8
Opt-3			1195.8	1199.2	706.8	492.4	2.429						2625	12.0
						Avg	2.427					Avg	2550	11.8

Mix Design Sheet

Based on laboratory Information, Calculate the Volumetrics for the Marshall Mix Design Sheet.

Two Rice Gravities (Gmm) (AASHTO T-209) were performed at 4.0% and 4.5% Asphalt Content.

4.0% = 2.529

4.5% = 2.513

MAXIMUM SPECIFIC GRAVITY OF BITUMINOUS PAVING MIXTURES (AASHTO T-209)

Project Ref. No.	2002 School Design	Date	01/15/02
Project No.	20021-2002-06	Region	3
Contract No.	2002	County	Davidson
Contractor	Mix Design	Subcontractor	#REF!
State Route No.	6	Date of Letting	Nov. 27,2001

Mix Type 307-BM w/ RAP PG 64-22

CALCULATION OF MAXIMUM SPECIFIC GRAVITY:

FLASK % AC	4.0	4.2	4.5
WT. DRY SAMPLE + FLASK	4204.8	4216.9	4221.2
WT. FLASK	2178.5	2178.5	2178.5
WT. DRY SAMPLE (A)	2026.3	2038.4	2042.7
WT. FLASK FILLED WITH WATER (D)	7401.3	7401.3	7401.3
WT. FLASK FILLED WITH WATER & DRY SAMPLE (E)	8626.4	8633.4	8631.1
MAXIMUM SPECIFIC GRAVITY MIX (G_{mm}) = $\frac{A}{A+D-E}$ ⇒	**2.529**	**2.528**	**2.513**

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Mix Design Sheet

Based on laboratory Information, Calculate the Volumetrics for the Marshall Mix Design Sheet.

Bulk Specific Gravities (Gmb) were performed for all **Specimens** Then averaged for each Asphalt Content 3.5%, 4.0%, 4.5%, 5.0% and 5.5%.

3.5% = 2.404
4.0% = 2.421
4.5% = 2.434
5.0% = 2.447
5.5% = 2.451

	Bulk SG
	2.410
	2.404
	2.399
Avg	2.404
	2.416
	2.418
	2.427
Avg	2.421
	2.435
	2.434
	2.434
Avg	2.434
	2.448
	2.444
	2.447
Avg	2.447
	2.450
	2.452
	2.450
Avg	2.451

Based on laboratory Information, Starting at an Asphalt content were a rice gravity has been performed. Calculate the (Gse) Effective Specific Gravity of the Aggregates.

Effective Specific Gravity of the Aggregates

Gmm from AASHTO T- 209 (Rice Gravity) for 4.0 % Asphalt C

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

ective Specific Gravity of the Aggregates

t by Mass of Total Loose Mixture (100.0)

ontent % by Total Mass of Mixture (4.0)

Effective Specific Gravity of the Aggregates

Using AASHTO T- 209 (Rice Gravity) for Gmm @ 4.0 % Asphalt Content

$$G_{se} = \frac{100 - 40}{\frac{100}{2.532} - \frac{4.0}{1.032}} = \frac{96.0}{39.494} = \frac{96.0}{3.876} = 2.696$$

Mix Des. Data

State of Tennessee Marshall Mix Design Sheet

Type of Mix	307-BM w/ RAP PG 64-22	Contract No.	2002	Contractor	Mix Design
County	Davidson	Date	1/15/2002	Effective Gravity of Aggregate	2.696
Project Ref. No.	2002 School Design	Region	3	SG of Asphalt	1.032

Gse = Effective Specific Gravity of the Aggregates stays the same for all Asphalt Contents.

Va or VTM

% Air Voids or Voids in Compacted Mix

$$V_a = 100 \times \frac{G_{mm} - G_{mb}}{G_{mm}}$$

Va = Volume of air voids in %

Gmm = Maximum Specific Gravity of the Compacted Mixture using Rice Gravity @ 4.0 % A.C. (2.532)

Gmb = Bulk Specific Gravity of the Compacted Mixture the avg. of three specimens @ 4.0 % A.C. (2.421)

Va or VTM
% Air Voids or Voids in Compacted Mix

@ 4.0 % Asphalt Content

$$V_a = 100 \times \frac{2.532 - 2.421}{2.532} = 100 \times \frac{0.111}{2.532}$$

$$= 100 \times 0.0438 = 4.4\%$$

Sample			Mass (grams)			Volume		Rice SG	VTM
					In				
2-1	4.0	96.0	1199.1	1202.8	706.5	496.3	2.416	2.532	4.4
2-2			1202.1	1206.3	709.2	497.1	2.418		
2-3			1195.7	1199.0	706.4	492.6	2.427		
						Avg	2.421		

VMA
Voids in Mineral Aggregate

@ 4.0 % Asphalt Content

$$VMA_{eff} = 100 - \frac{G_{mb} \times P_s}{G_{se}}$$

Vma $_{eff}$ = Voids in Mineral Aggregates using Effective Specific Gravity of the Aggregates

Gmb = Bulk S pecific Gravity of the Compacted Mixture the avg. of three specimens @ 4.0 % A.C. (2.421)

Ps = Percent Aggregate content (96.0)

Gse = Effective Specific Gravity of the Aggregates (2.696)

VMA
Voids in Mineral Aggregate

@ 4.0 % Asphalt Content

$$VMA_{eff} = 100 - \frac{2.421 \times 96.0}{2.696}$$

$$= 100 - \frac{232.416}{2.696} = 100 - 86.2 = 13.8$$

Sample No.	% AC	% Agg.	Mass (grams) In Air	Mass (grams) SSD	Mass (grams) In Water	Volume (ml)	Bulk SG	Rice SG or TMD	VTM (%)	VMA (%)
2-1	4.0	96.0	1199.1	1202.8	706.5	496.3	2.416	2.532	4.4	13.8
2-2			1202.1	1206.3	709.2	497.1	2.418			
2-3			1195.7	1199.0	706.4	492.6	2.427			
						Avg	2.421			

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VFA
Voids Filled with Asphalt

@ 4.0 % Asphalt Content

$$VFA_{eff} = 100 \times \frac{VMA_{eff} - V_a}{VMA_{eff}}$$

VFA_{eff} = Voids Filled with Asphalt using VMA eff
VMA_{eff} = Voids in Mineral Aggregates using Effective Specific Gravity of the Aggregates (13.8)
Va = Volume of air voids in % (4.4)

*** VFA_{eff} = TDOT Definition**

VFA
Voids Filled with Asphalt

@ 4.0 % Asphalt Content

$$VFA_{eff} = 100 \times \frac{13.8 - 4.4}{13.8} = 100 \times \frac{9.4}{13.8}$$

$$= 100 \times 0.680 = 68.0$$

Sample No.	% AC	% Agg.	Mass (grams) In Air	Mass (grams) SSD	Mass (grams) In Water	Volume (ml)	Bulk SG	Rice SG or TMD	VTM (%)	VMA (%)	VFA (%)
2-1	4.0	96.0	1199.1	1202.8	706.5	496.3	2.416	2.532	4.4	13.8	68.0
2-2			1202.1	1206.3	709.2	497.1	2.418				
2-3			1195.7	1199.0	706.4	492.6	2.427				
						Avg	2.421				

TN TDOT Department of Transportation

How to Calculate Gmm (Maximum Theoretical Specific Gravity of Paving Mixture) at all other Asphalt Contents

Two Rice Gravities (Gmm) (AASHTO T-209) were performed at 4.0% and 4.5% Asphalt Content.

4.0% = 2.532

4.5% = 2.513

The other Gmm (Maximum Theoretical Specific Gravities of Paving Mixture) can be calculated at all other Asphalt Contents.

3.5% = ?

5.0% = ?

5.5% = ?

Rice SG or TMD
2.552
2.532
2.513
2.494
2.476

TN TDOT Department of Transportation

How to Calculate Gmm (Maximum Theoretical Specific Gravity of Paving Mixture) at all other Asphalt Contents

Calculate the Gmm (Maximum Theoretical Specific Gravity of Paving Mixture) @ 3.5 % Asphalt Content

$$G_{mm} = \frac{P_{mm}}{\frac{P_s}{G_{se}} + \frac{P_b}{G_b}}$$

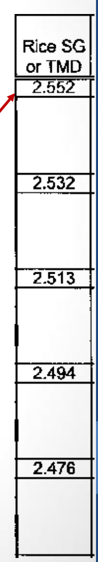
Gmm = Maximum Specific Gravity of the Compacted Mixture
Pmm = Percent by Mass of Total Loose Mixture (100.0)
Ps = Percent Aggregate Content (96.5)
Gse = Effective Specific Gravity of the Aggregates (2.696)
Pb = Asphalt Content % by Total Mass of Mixture (3.5)
Gb = Gravity of the Asphalt Cement (1.032)

How to Calculate Gmm (Maximum Theoretical Specific Gravity of Paving Mixture) at all other Asphalt Contents

@ 3.5 % Asphalt Content

$$G_{mm} = \frac{P_{mm}}{\frac{P_s}{G_{se}} + \frac{P_b}{G_b}} = \frac{100}{\frac{96.5_s}{2.696} + \frac{3.5}{1.032}}$$

$$= \frac{100}{35.497 + 3.391} = \frac{100}{39.186} = 2.552$$



Rice SG or TMD
2.552
2.532
2.513
2.494
2.476

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TN TDOT Department of Transportation

Volumetrics

Example

TN TDOT Department of Transportation

CALCULATION OF MAXIMUM SPECIFIC GRAVITY:

		(1)	(2)	(3)
FLASK	% AC	5.9		
	WT. DRY SAMPLE + FLASK (grams)	3927.7		
	WT. FLASK (grams)	2177.7		
	WT. DRY SAMPLE (A) (grams)	1750.0		
	WT. FLASK FILLED WITH WATER (D) (grams)	7399.0		
	WT. FLASK FILLED WITH WATER & DRY SAMPLE (E) (grams)	8423.7		
		2.413		

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CALCULATION OF THE EFFECTIVE GRAVITY OF THE AGGREGATES:

% AGGREGATES	94.1		
SPECIFIC GRAVITY OF ASPHALT CEMENT	1.032		
	2.635		

Effective Specific Gravity of Aggregates (G_{se})

$$Gse = \frac{94.1}{41.4 - 5.7}$$

Avg. Effective Gravity 2.635

RICE VALUES AT OTHER ASPHALT CONTENTS

Percent Asphalt	Theoretical Maximum Density
7.0	2.376
6.5	2.393
6.0	2.410
5.5	2.427
5.0	2.445

$$GGmm = \frac{100}{42.077\ .783}$$

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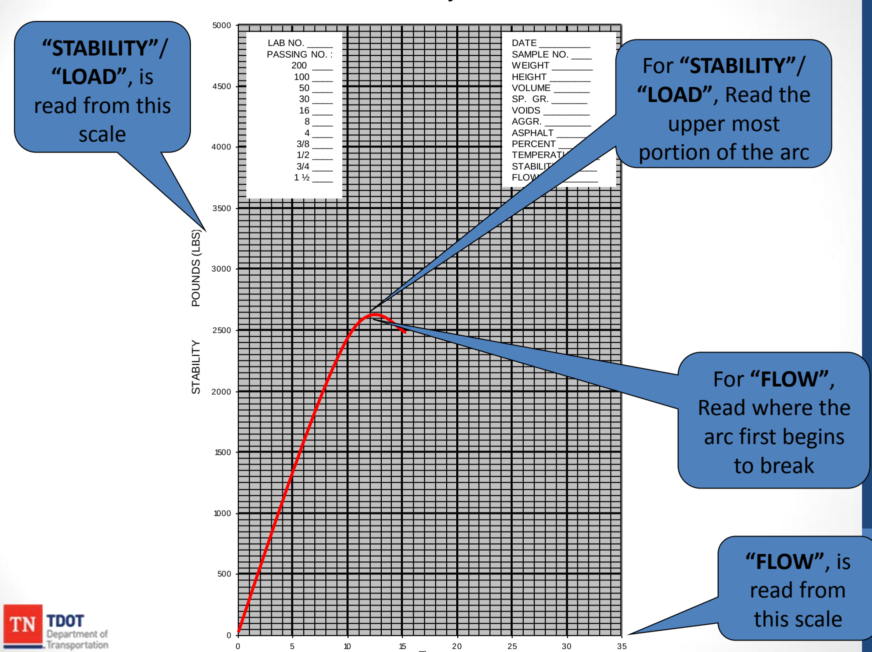
Marshall Stability/Flow Chart



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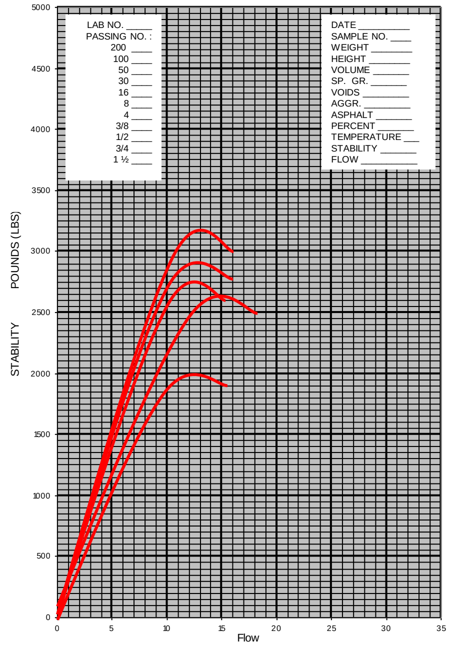
Marshall Stability/Flow Chart



As a rule, not a Spec., if one of the samples reads a 500+/- lbs difference than the others, you can discard it and average the remaining two.

This would be a preferred read

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Contractor Watts Paving INC
Effective Gravity of Agg (G_{se}) 2.635
SG of Asphalt (G_b) 1.032
Number of Blows w/Marshall Hammer 75

From bottom section of T-209(rice)

Sample No.	P_b % AC	P_s % Agg.	Mass (grams) In Air	Mass (grams) SSD	Mass (grams) In Water	Volume (ml)	G_{mb} Bulk SG	G_{mm} Rice SG	V_a (%)	VMA (%)	VFA (%)	Unit Weight (pcf)	Stability (lb)	Flow (0.01")
1-1	5.0	95.0	1177.2	1181.4	666.2	515.2	2.285	2.445	6.4	17.5	63.3	142.7	2750	10.0
1-2			1179.6	1183.9	668.7	515.2	2.290						2800	9.0
1-3			1175.8	1178.9	665.0	513.9	2.288						2850	9.0
						Avg	2.288						2800	9.3
2-1	5.5	94.5	1181.4	1183.9	668.0	515.9	2.290	2.247	5.2	17.4	70.4	143.7	2650	11.0
2-2			1178.2	1181.5	669.2	512.3	2.300						2700	10.0
2-3			1177.4	1179.3	671.2	508.1	2.317						2725	10.0
						Avg	2.302					Avg	2692	10.3
3-1	6.0	94.0	1182.1	1183.0	672.3	510.7	2.315	2.410	3.8	17.3	78.1	144.7	2625	12.0
3-2			1180.4	1181.2	674.1	507.1	2.328						2650	12.0
3-3			1181.6	1182.6	672.0	510.6	2.314						2600	12.0
						Avg	2.319					Avg	2625	12.0

Preparing Graphs and Selecting Optimum

Preparing Graphs

- With all of the Marshall Specimens prepared at varying AC contents, tests can be preformed on them to determine various design parameters.
- These numbers (VTM, VMA, etc.) will be utilized to select numbers for the mix design.

State of Tennessee Marshall Mix Design Sheet

Type of Mix: 411-D PG 64-22	Contract No.: CNE315	Contractor: Concrete Structures	
County: Hickman	Date: 3/13/2008	Effective Gravity of Aggregate: 2.614	
Project Ref. No.: BR-STP-48(21)	Region: 3	SG of Asphalt: 1.032	
HMA Producer: EUBANK ASPHALT, DICKSON PLANT #1		Number of Blows w/ Marshall Hammer: 75	

Sample No.	% AC	% Agg.	Mass (grams) In Air	SSD	In Water	Volume (ml)	Bulk SG	Rice SG or TMD	VTM (%)	VMA (%)	VFA (%)	Unit Weight (pcf)	Stability (lb)	Flow (0.01")
1-1	5.0	95.0	1160.7	1161.7	636.7	525.0	2.211	2.428	8.9	19.6	54.7	138.0	3275	9.5
1-2			1156.6	1157.9	635.8	522.1	2.215						3900	10.5
1-3			1164.4	1165.6	638.7	526.9	2.210						3700	11.0
						Avg	2.212					Avg	3625	10.3
2-1	5.5	94.5	1157.4	1158.3	645.8	512.5	2.258	2.411	6.3	18.3	65.7	141.0	2750	12.0
2-2			1161.2	1162.0	647.5	514.5	2.257						2400	9.5
2-3			1160.8	1161.7	648.6	513.1	2.262						3175	10.0
						Avg	2.259					Avg	2775	10.5
3-1	5.9	94.1	1160.6	1161.3	655.8	505.5	2.296	2.397	4.1	17.2	76.3	143.5	2050	9.0
3-2			1155.4	1156.2	653.6	502.6	2.299						2600	9.5
3-3			1159.8	1160.7	657.0	503.7	2.302						2400	10.0
						Avg	2.299					Avg	2350	9.5
4-1	6.0	94.0	1161.4	1162.3	659.2	503.1	2.308	2.394	3.7	17.1	78.2	143.8	2125	10.0
4-2			1159.0	1159.5	657.0	502.5	2.306						1950	10.0
4-3			1159.3	1159.9	655.5	504.4	2.298						2250	10.0
						Avg	2.304					Avg	2108	10.0
5-1	6.5	93.5	1155.3	1155.8	663.9	491.9	2.349	2.377	1.2	16.0	92.5	146.5	1875	8.5
5-2			1159.3	1159.9	667.0	492.9	2.352						1875	9.5
5-3			1162.7	1163.4	667.5	495.9	2.345						1750	11.0
						Avg	2.348					Avg	1833	9.7
Opt-1	5.9	94.1	1160.6	1161.3	655.8	505.5	2.296	2.397	4.1	17.2	76.3	143.5	2050	9.0
Opt-2			1155.4	1156.2	653.6	502.6	2.299						2600	9.5
Opt-3			1159.8	1160.7	657.0	503.7	2.302						2400	10.0
						Avg	2.299					Avg	2350	9.5

Preparing Graphs

- All of the following parameters from the Marshall Sheet are plotted versus AC percentage:
  - Void in the Mixture (VTM)
  - Void in Mineral Aggregate (VMA)
  - Voids Filled with Asphalt (VFA)
  - Unit Weight
  - Marshall Stability
  - Marshall Flow

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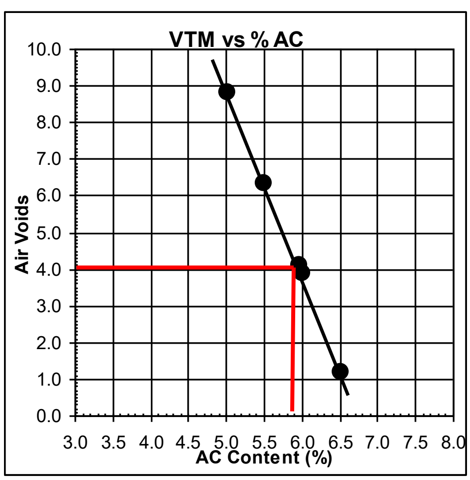
Preparing Graphs

- The most important graph is the plot of AC content vs. Air Voids, which is used to select the optimum binder content of the mixture.

Preparing Graphs

Drawing a best fit line.

Verify your optimum



Typical design set at 4% air voids.

Looks like 5.9% AC will give us the voids we want.

Preparing Graphs

- Plot the rest of the data (VMA, VFA, Unit Weight, Stability, and Flow) to observe the mixture behavior and make sure the mix will meet specifications.

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Voids in Mineral Aggregate (VMA)

- Most mixes we design have a VMA spec.
- What is the VMA spec for:

411-D?	***Min. 14%***
307-BM2?	***Min. 13.5%***

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Voids in Mineral Aggregate (VMA)

- VMA graphs are typically U-shaped curves.
- As we add hot AC to mixtures, it "lubricates" the aggregate and helps it compact, thus reducing the Voids in the Aggregate structure.
- However, at some point, adding AC only "spreads" the aggregate out, then *increasing* VMA.
- As a result, we prefer to select an optimum AC that lands on the LEFT side of the VMA curve.

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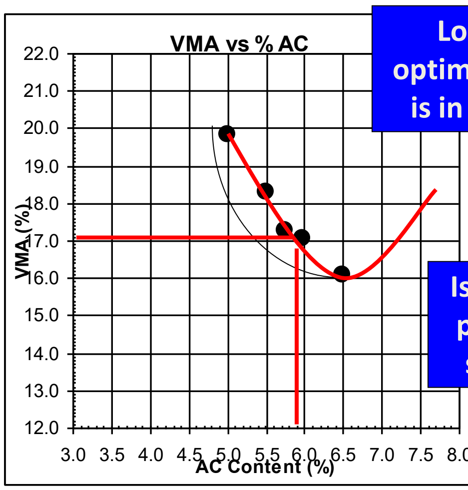
Voids in Mineral Aggregate (VMA)



Looks like our optimum of 5.9% AC is in a good place.

Is our mix going to pass TDOT's VMA spec. for 411-D?

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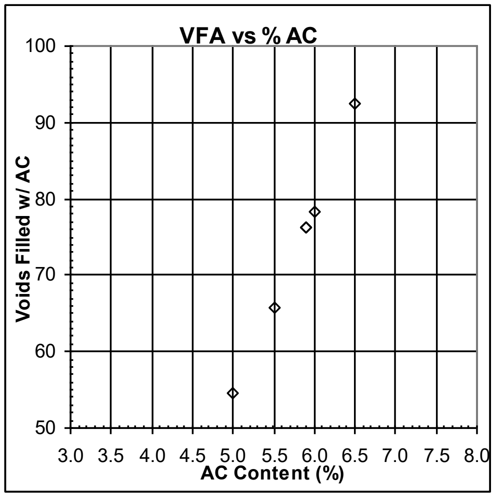
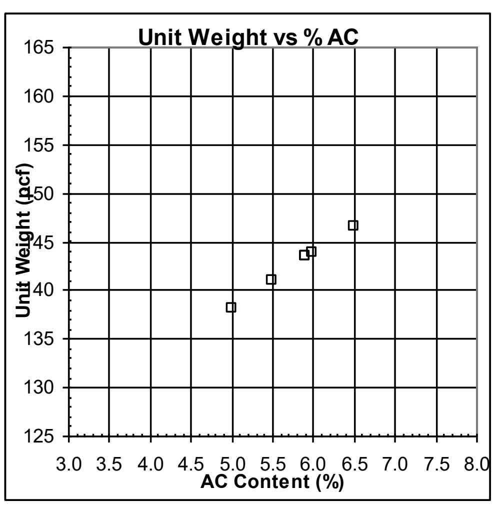
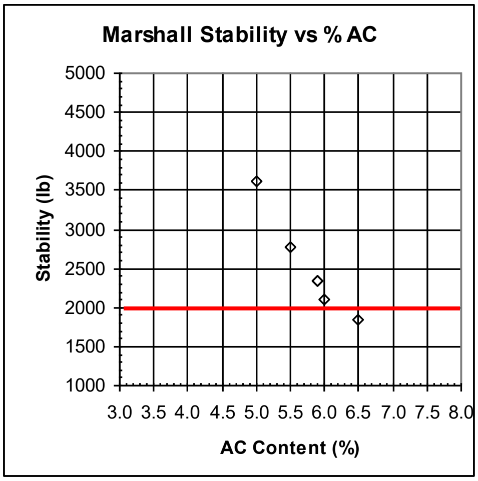
Voids Filled with Asphalt (VFA)



Unit Weight



Marshall Stability



How does this compare to the 411-D stability spec?

Is there any AC content that would not meet spec?

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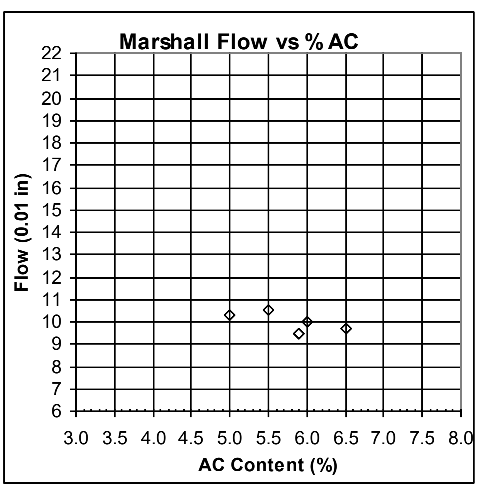
Marshall Flow



Are these acceptable numbers for flow?

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Critical Mix Criteria

- Now that an optimum has been selected and checked graphically, there is a need to verify the sensitivity of the mix.

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Critical Mix Criteria

TDOT Specs 407.03, (C), n.

"In order to identify critical mixes and make appropriate adjustments, the mix design shall have the required design properties for the bitumen content range of Optimum Asphalt Cement ±0.25%

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Critical Mix Criteria

- An AC content versus Air Voids graph that is too steep of a slope should be avoided if possible.
- Otherwise, a slight change in asphalt content could mean a big change in air voids.

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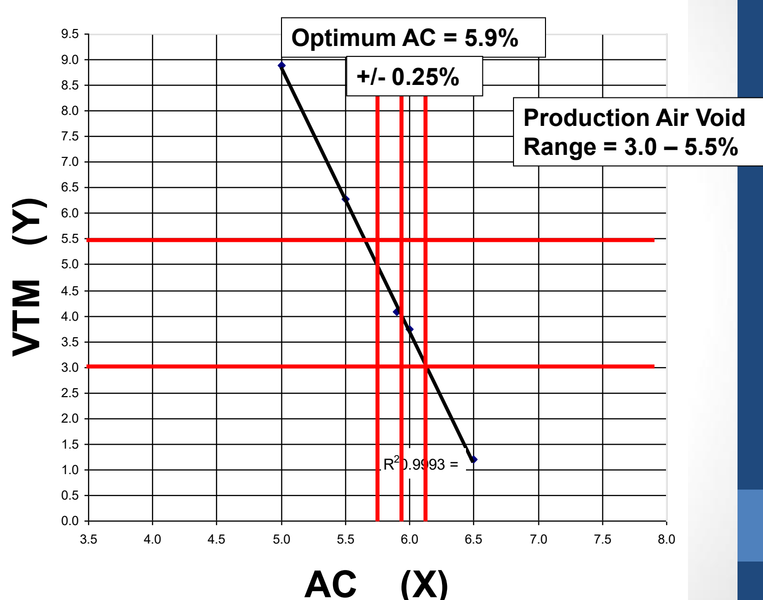
Critical Mix Graph



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Critical Mix Criteria

- Are any of the plots outside of the allowable void content for production when 0.25% AC is added or subtracted?
- What could be done to the design to correct it?

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Testing Asphalt Mix

Part 2

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ASTM D-4867

Standard Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures

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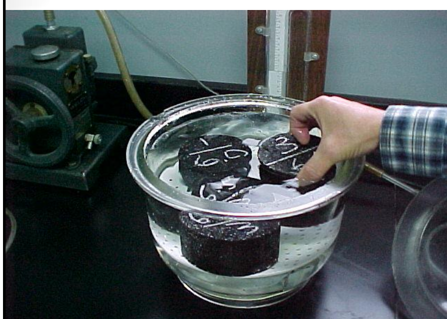
ASTM D-4867

ASTM D-4867



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ASTM D-4867

- Some asphalt mixtures can be moisture susceptible.
- TDOT specifications establish a minimum Tensile Strength Ratio (TSR) of 80%.

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ASTM D-4867

Compact 6 Marshall Specimens at a void range of 6% to 8%.

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ASTM D-4867

- Specimens with higher voids (6-8%) are needed for the TSR, which vary from the typical 4%.
- Trial batches will need to be ran to estimate the number of blows needed to achieve specimens within the higher range.

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Number of Blows

For an example, assume that the TSR blow count will be somewhere between 15 to 35.

Sample I.D.		15	25	35
Diameter (inches)	D	4.0	4.0	4.0
Thickness (inches)	t	N/A		
Dry mass in air	A	1145.7	1144.5	1144.2
SSD mass	B	1151.9	1148.3	1146.0
Mass in water	C	630.4	633.1	636.3
Volume (B-C)	E			
Bulk Sp. Gr. (A/E)	F			
Maximum Sp. Gr.	G	2.392	2.392	2.392
% Air Void (100((G-F)/G))	H			

This is a good range, which will help estimate what is needed to get 7%.

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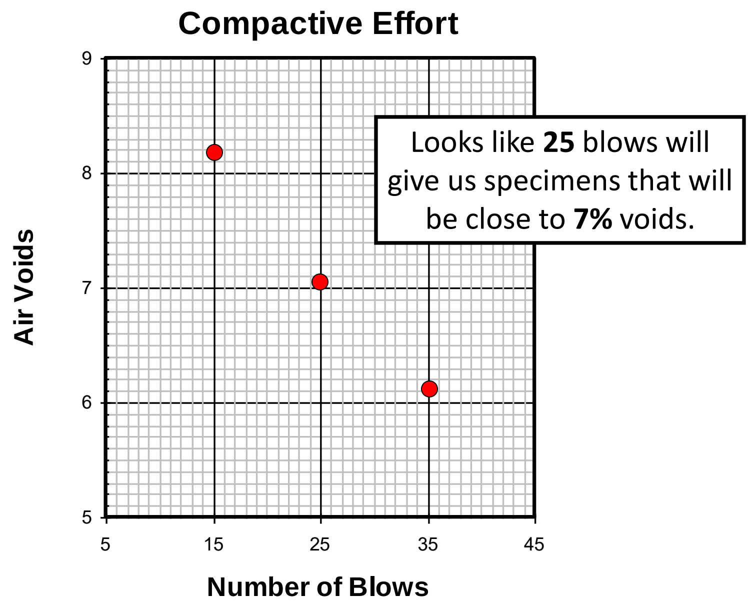

Making TSR Specimens

Are my pills going to be the same height as before?

➔ *Possibly not.*

Do they need to be?

➔ *Yes.*

Marshall Test Specimen

Measure the *Height* of Compacted Marshall Specimen. (Avg. of 3 locations)

It should measure *2.5 ± 0.05* inches.

If it does not meet this requirement adjust the weight before preparing other Marshall specimens.

Formula:

$$\text{Adjusted Weight} = \frac{2.5}{\text{Specimen Height}} \times \text{Initial Weight}$$

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Example:

Initial Weight = 1200 grams

Measured Height = 2.60 inches

$$\textit{Adjusted weight} = \frac{2.5}{2.60} * 1200$$

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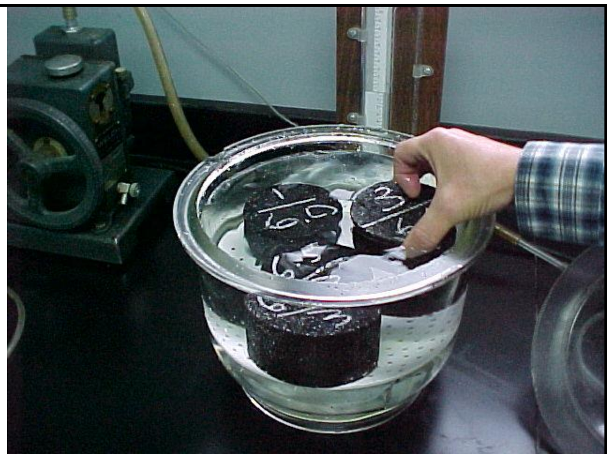
Now saturate the subset in a container of water by using a vacuum to pull water into the specimens for just a few seconds.

The acceptable saturation range is from 55% to 80 % of the volume of air voids for each specimen.



If, after the initial vacuum, the saturation is less than 55 %, then the vacuum must be reapplied. What if it is greater than 80 %?

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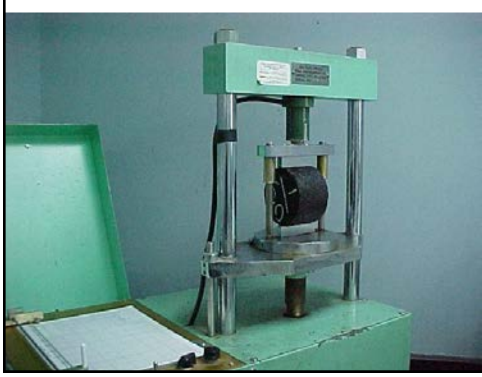
While the unconditioned (dry) subset sits on a shelf, the conditioned (wet) subset is placed in a 140°F water bath for 24 hours.



At the end of the conditioning period, both subsets are brought back to 77° and then tested using the indirect tensile breaking head.

Ten Minute Boil Test Antistrip Additive

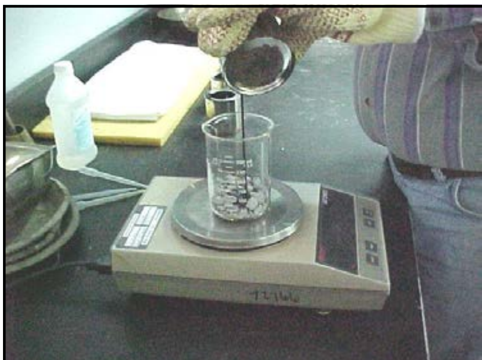
(Field Test / Laboratory Test)

Referenced in TDOT Specifications section 407.03 (E)

Ten Minute Boil Test

Prepare approximately 500 g of +4 material. Weigh out approx. 100 g of agg. into three 400 mL beakers. Heat agg. and approx. ¾ qt. of AC to 300 ± 10º F for 30 minutes. Prepare two smaller cans with 0.3% and 0.5% of the selected additive.

Add 100 g of hot AC to each small can. A third can will contain AC only. Stir the AC and anti-strip thoroughly.



Add 100 g of hot aggregate to each beaker. Thoroughly blend 5 g of AC with the 100 g in the beaker.

Pour out onto separate pieces of waxed paper labeled with additive amounts. Allow mixture to cool to room temperature.

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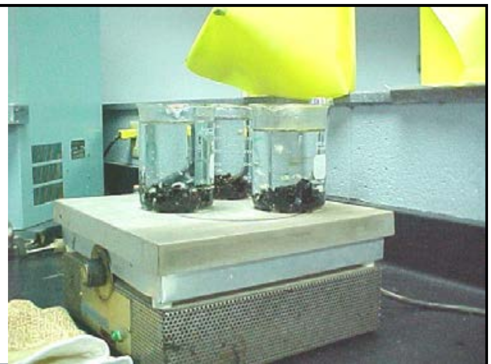
Bring water to a boil in a 600 mL beaker. Place the cooled mixture into the water and boil for 10 minutes. After 10 minutes, place the mixture onto clean pieces of paper and allow to cool.



Visually inspect material for evidence of stripping. Choose lowest rate with no evidence of stripping.

Which has more stripping?

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Testing Asphalt Mix

Part 3

TN TDOT Department of Transportation

AASHTO T-308

AASHTO T-308

- Furnace must be calibrated to each different mix.
- Use of furnace must be backed up weekly with a solvent extraction.
- Test is to be run at 538° C.
- Watch for broken aggregate.

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AASHTO T-308

Begin by determining the correct sample size for the HMA being tested (T-308 TABLE 1).

Split the sample evenly between the two sample basket.

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AASHTO T-308

Spread the material into a thin, even layer to ensure complete ignition of the binder.

Stack baskets and lock cover into place.

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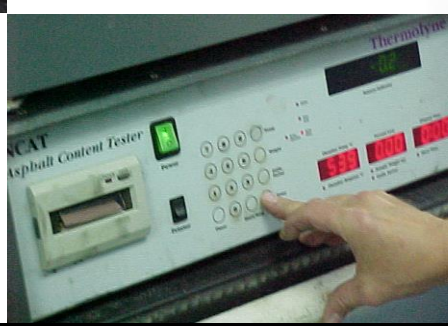
AASHTO T-308

Place the basket/sample assembly into the furnace. Be careful not to let the assembly touch any part of the furnace wall.

Enter the sample mass, the testing temperature, and the pre-determined correction factor. Furnace will stop test when AC content is determined.



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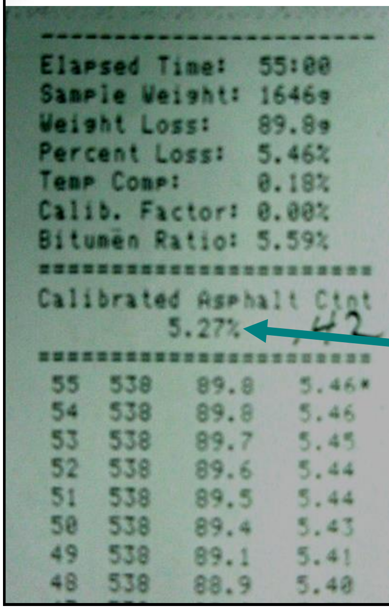
AASHTO T-308



(Before Burnout)	
Total Wt. Sample & Basket	5000.0
Basket Wt.	3000.0
Wt. of Sample	2000.0
(After Burnout)	
Total Wt. Sample & Basket	4891.6
Basket Wt.	3000.0
Wt. of Sample	1891.6
Design A. C.	5.4
A. C. Content from N.C.A.T.tape	5.27
A.C. Content Deviation	**-0.13**

AASHTO T-308

Table A2.1—Permitted Sieving Difference

Sieve	Allowable Difference
Sizes larger than or equal to 2.36 mm (No. 8)	±5.0 percent
Sizes larger than 0.075 mm (No. 200) and smaller than 2.36 mm (No. 8)	±3.0 percent
Sizes 0.075 mm (No. 200) and smaller	±0.5 percent

Nominal Maximum Aggregate Size, mm	Sieve Size	Minimum Mass of Specimen, g
4.75	No. 4	1200
9.5	3/8 In.	1200
12.5	1/2 In.	1500
19.0	3/4 In.	2000
25.0	1 in.	3000
37.5	1 ½ in.	4000

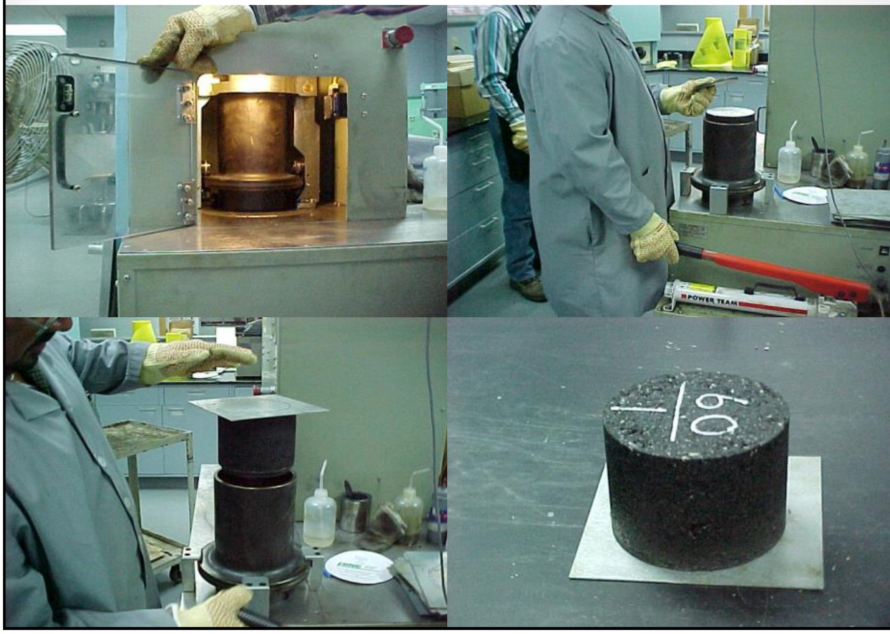
Table 903.06-4: Hot Plant Mix Leveling Course
Mixture Design Range of Gradations

Sieve Size	Total Per Cent Passing, by Weight				
	Grading BM	Grading BM2 (1)	Grading C	Grading CW	Grading CS
1-1/4 inch	--	100	--	--	--
1 inch	100	--	--	--	--
3/4 inch	85-100	81-93	100	100	--
3/8 inch	59-79	57-73	70-90	75-100	100
No. 4	42-61	40-56	39-66	--	89-94
No. 8	29-47	28-43	23-47	43-67	53-77
No. 30	13-27	13-25	10-27	23-47	23-42
No. 50	7-20	9-19	8-15	--	--
No. 100	4-10	6-10	4-8	4-10	9-18
No. 200	0-6.5	2.5-6.5	2.5-6.5	2.5-6.5	6-13.5

TN TDOT Department of Transportation

AASHTO T-312

AASHTO T-312



6

Handouts

1) Maximum Specific Gravity of Mix

$$Gmm = \frac{Pmm}{\left(\frac{Ps}{Gse}+\frac{Pb}{Gb}\right)}$$

Gmm = Max Specific Gravity of mix
Gb = Gravity of asphalt cement
Pmm = Percent by mass of loose mix
Ps = Percent (%) Agg. Content
Gse = Effective specific gravity of Agg.
Pb = Asphalt content % by total mass of mix

2) Volume of Air Voids in Marshall's

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

Va = Volume of air voids
Gmm = Max Specific Gravity of mix
Gmb = Bulk gravity of mix

3) Volume of Voids in Mineral Agg.

$$Vma(eff.) = 100 - \frac{(Gmb \times Ps)}{Gse}$$

Vma = Volume of voids in mineral Agg.
Ps = Percent (%) Agg. Content
Gse = Effective specific gravity of Agg.
Gmb = Bulk gravity of mix

4) Volume of Voids Filled with Asphalt

$$Vfa(eff.) = 100 \times \frac{(Vma - Va)}{Vma}$$

Vfa = Voids filled with AC
Va = Volume of air voids
Vma = Volume of voids in mineral Agg.

5) Effective Asphalt Content by % Mix Mass

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

Pbe = Eff. AC (% by mass of mix)
Pba = Absorbed AC (% by mass of Agg.)
Pb = % Asphalt Content
Ps = % Agg. Content

6) Absorbed Asphalt Content by % Agg.

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

Pba = Absorbed AC (% by mass of Agg.)
Gse = Effective specific gravity of Agg.
Gb = Gravity of asphalt cement
Gsb = Bulk Specific Gravity of Agg.

7) Effective Specific Gravity of Agg.

$$Gse = \frac{(Pmm - Pb)}{\left(\frac{Pmm}{Gmm}-\frac{Pb}{Gb}\right)}$$

Gse = Effective specific gravity of Agg.
Pb = Asphalt content % by total mass of mix
Gmm = Max Specific Gravity of mix
Gb = Gravity of AC
Pmm = % by mass of loose mix.

8) Blending of Agg. / Proportioning Agg.

$$P = Aa + Bb + Cc + \cdots$$

A,B,C,… = % of Agg.passing a given sieve
a,b,c,… = Proportions of Agg. A,B,C,…

9) RAP Blending Calculation

$$M(rap) = \frac{(P(rap) \times M(tot))}{(100 - Pb(rap))}$$

M(rap) = Mass of RAP
P(rap) = % of RAP in Mix
M(tot) = Total mass of Agg. in mix
Pb(rap) = % AC contributed by RAP

10) Mass of Virgin Asphalt Needed

$$M(acpb) = \left(\frac{M(tot)}{\left(\frac{100-Pb}{100}\right)}\right) - \left(\frac{(M(rap)\times Pb(rap))}{100}\right) - M(tot)$$

M(acpb) = Mass of Virgin AC
M(rap) = Mass of RAP
Pb(rap) = % Asphalt Content in RAP
Pb = % Asphalt Content
M(tot) = Total mass of Agg. in mix

ABBREVIATIONS	
G_b	Specific **G**ravity of an Asphalt **B**inder
G_{mb}	**B**ulk Specific **G**ravity of an Asphalt **M**ixture
G_{mm}	**M**aximum Theoretical Specific **G**ravity of an Asphalt **M**ixture (Rice Gravity)
G_{sa}	**A**pparent Specific **G**ravity of an Aggregate (**S**tone)
G_{sb}	**B**ulk Specific **G**ravity of an Aggregate (**S**tone)
G_{se}	**E**ffective Specific **G**ravity of an Aggregate (**S**tone)
M	Total **M**ass of an Asphalt Mixture
M_{ACPb}	**M**ass of an Binder at a known **A**sphalt **C**ontent (**P_b**)
M_{agg}	**M**ass of **Agg**regate
M_{air}	**M**ass of **Air** (Equivalent to zero grams)
M_b	**M**ass of Asphalt **B**inder
M_{be}	**M**ass of **E**ffective Asphalt **B**inder
M_{RAP}	**M**ass of **RAP** material added in the blend.
M_{tot}	**Tot**al **M**ass of Aggregate Blend
M_{xy}	**M**ass of a given aggregate <u>size</u> <u>fraction</u> to the blended pan
P_b	**B**inder Content (**P**ercent by total mass of mixture)
P_{bRAP}	**P**ercent **B**inder of the **RAP**
P_{ba}	**A**bsorbed **B**inder Content (**P**ercent by mass of aggregate)
P_{be}	**E**ffective **B**inder Content (**P**ercent by total mass of mixture)
P_{iry}	**P**ercent **I**ndividually **R**etained on a given sieve "**y**"
P_{mm}	**P**ercent by **M**ass of Total Loose **M**ixture (Equivalent to 100%)
P_{RAP}	**P**ercent of **RAP** Aggregates contributing to the blend.
P_s	Aggregate (**S**tone) Content (**P**ercent by total mass of mixture)
P_x	**P**ercent of Aggregate <u>Stockpile</u> contributing to the blend.
SSD	**S**aturated **S**urface **D**ry
V_a	**V**olume of **A**ir Voids (Percent of total volume)
V_b	**V**olume of Asphalt **B**inder
V_{ba}	**V**olume of **A**bsorbed Asphalt **B**inder
V_{fa}	**V**olume of Voids **F**illed with **A**sphalt
V_{ma}	**V**olume of Voids in **M**ineral **A**ggregate
V_{mb}	**B**ulk **V**olume of Compacted **M**ixture
V_{mm}	Voidless **V**olume of Asphalt **M**ixture (at Theoretical **M**aximum Gravity)
V_{sb}	**V**olume of Mineral Aggregate (by **B**ulk **S**pecific Gravity)
V_{se}	**V**olume of Mineral Aggreagte (by **E**ffective **S**pecific Gravity)