Tennessee Department of Transportation
Division of Materials and Tests

Hot Mix Asphalt Mix Design Certification

February 25, 2013

Tennessee Department of Transportation – TDOT
Hot Mix Asphalt (HMA) Mix Design Methods

Class Schedule

DAY	TIME	TOPIC
Monday	9:00 – 10:00	Registration
	10:00 – 10:15	Mix Design Workshop (Introduction)
	10:15 – 11:00	Basic Materials
	11:00 – 12:00	Overview of Designing TDOT Mixes
	12:00 – 1:15	Lunch
	1:15 – 2:30	Testing Aggregates – Part 1: T2, T248, T11, T27
	2:30 – 2:45	Break
	2:45 – 3:45	Batching Aggregates
Tuesday	8:00 – 8:30	Homework Review
	8:30 – 9:30	Testing Aggregates – Part 2:
	9:30 – 9:45	Break
	9:45 – 10:45	*Lab Demo:* T11, T27, Loss on Ignition, T 84, T 85, FF Count, Glassy Particle, F&E
	10:45 – 11:45	T 84, T 85 Calculations
	11:45 – 1:00	Lunch
	1:00 – 2:00	0.45 Power Curves
	2:00 – 2:15	Break
	2:15 – 3:00	Testing Mix – Part 1: T166, T209, T245
Wednesday	8:00 – 8:30	Homework Review
	8:30 – 10:00	*Lab Demo*: T 166, T 209, and T 245
	10:00 – 10:15	Break
	10:15 – 11:45	Volumetric Calculations
	11:45 – 1:00	Lunch
	1:00 – 2:30	Preparing Graphs Selecting Optimum Asphalt Content Checking Critical Mix Criteria
	2:30 – 2:45	Break
	2:45 – 4:00	Testing Mix – Part 2: ASTM D4867, 10 Min Boil Test

DAY	**TIME**	**TOPIC**
Thursday	8:00 – 8:30	Homework Review
	8:30 – 9:45	L*ab Demo*: ASTM D 4867, 10 Min Boil Test
	9:45 – 10:00	Break
	10:00 – 10:45	Testing Mix – Part 3: T308, T312
	10:45 – 11:45	Mix Design Software Submitting a Design
	11:45 – 1:00	Lunch
	1:00 – 2:15	Review of Test Methods
	2:15 – 2:30	Break
	2:30 – 4:00	Review of TDOT Specifications
Friday	8:30 – 9:00	Questions and Answers
	9:15 – 4:00	Test

INTRODUCTION

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TENNESSEE DEPARTMENT OF TRANSPORTATION

MIX DESIGN WORKSHOP

WELCOME!

- How long is this class?
- When do classes start/ end each day?
- Bathrooms?
- Smoke breaks?
- What's for lunch?

Mix Design Workshop

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

Mix Design Workshop

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

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!!

TDOT Asphalt Qualifications are:

1) **ASPHALT CONCRETE MIX DESIGN TECHNICIAN**

TDOT Asphalt Qualifications are:

1) **ASPHALT CONCRETE PLANT TECHNICIAN**

TDOT Asphalt Qualifications are:

1) **ASPHALT CONCRETE 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 Cert# to the address you provided here on the sign-up sheet.

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.

TDOT
MATERIALS & TESTS DIVISION

BACKGROUND

- **Name**
- **Company**
- **Position within Company**
- **Experience with HMA testing/construction**

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QUESTIONS ?

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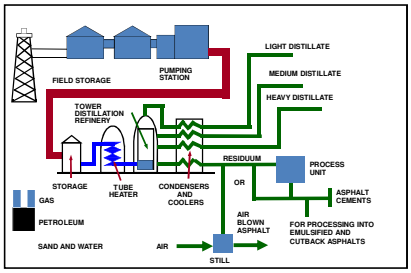
Basic Materials

Asphalt Mix Design Perspective

Materials

- Asphalt
  - Background
  - Properties
- Aggregate
  - Background
  - Properties

Refinery Operation



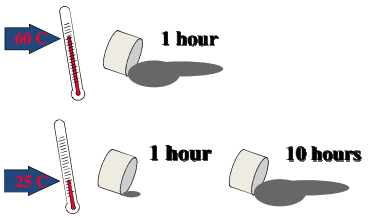
Distillation is used to separate the various crude fractions by boiling point ranges. The crude oil is heated in a large furnace to about 343 ^{o}C and partially vaporized. The remaining material is transferred to a distillation tower. Different fractions reach their boiling point ranges at various heights in the tower. When the temperature is reduced, each material condenses on a tray and is drawn off at each level.

How Asphalt Behaves

- Behavior Depends on
  - Temperature
  - Time of Loading
  - Age also important

Asphalt is a viscoelastic material. That is, it can both exhibit elastic and viscous properties at the same time.

Effect of Loading Time and Temperature



Asphalt is a viscoelastic material. This means that asphalt has the properties of both a viscous materials an elastic material. This property that asphalt exhibits, whether viscous, elastic or most often a combination of both, depends on temperature and time of loading. The effects of time and temperature are related. The behavior at high temperatures over short time periods is equivalent to what occurs at lower temperatures and longer times.

High Temperature Behavior

- High Temperature
  - desert climate
  - summer
- Sustained Loads
  - slow moving trucks
  - intersections

→ ***viscous liquid***

In hot conditions or under heavy loads, asphalt cements behave and flow like viscous liquids. Viscosity is the material characteristic used to describe the resistance of liquids to flow. Viscous liquids, like hot asphalt, are sometimes call plastic because once they start flowing the do not return to their original position.

Pavement Behavior - High Temperature

- Permanent Deformation is Concern
- Mixture is Plastic
  - wheel path rutting
  - shoving at intersections
- Depends on
  - asphalt cement (some)
  - mineral aggregate (lots)

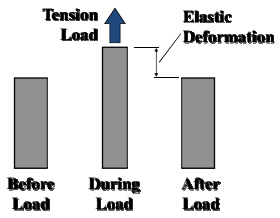
Low Temperature Behavior

- Low Temperature
  - cold climate
  - winter
- Rapid Loads
  - fast moving trucks

elastic solid

In cold climates or under rapid loading, asphalt cements behave like elastic solids. Elastic solids are like rubber bands. When loaded they deform and when unloaded they return to their original shape. Any elastic deformation is completely recoverable.

Elastic Behavior



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!!

Because asphalt cements are composed of organic molecules, they react with oxygen from the environment. This reaction is called oxidation and it changes the structure and composition of asphalt molecules. Oxidation causes asphalt cement to harden, hence the term oxidative hardening or age hardening.

Aging Behavior

- Volatilization - Short Term
  - volatile components evaporate during construction
- Physical Hardening
  - not aging…asphalt stiffens at low temps
  - reversible

Pavement Behavior - Aging

- Durability Cracks
- Mixture is Brittle
  - random, wandering cracks
- Depends on
  - asphalt cement (lots)
  - mineral aggregate (some)

Asphalt Binder Lab Temperatures

Ref: T.D.O.T. Spec. 407.03

Table A

PG Binder Grade	Lab Mix Temp	Lab Compaction Temp
64-22, 67-22	Per temp./visc. Chart	Per temp./visc. Chart
70-22	320° - 345° F	295° - 320° F
76-22	320° - 345° F	305° - 330° F
82-22	320° - 345° F	305° - 335° F

Mix Temperature:

Plant Production Temp.

- Must adhere to TDOT Spec 407.11, Table B:

Table B

PG Binder Grade	Minimum Temp.	Maximum Temp.
PG 64-22, PG 67-22	270° F(132° C)	310° F(154° C)
PG 70-22	290° F(143° C)	330° F(166° C)
PG 76-22	290° F(143° C)	330° F(166° C)
PG82-22	290° F(143° C)	330° F(166° C)

The temperature for Grading AS and Grading ACRL mixtures shall be between 225 and 275° F(110 and 135° C), except when modified binders are used, and then the temperatures shall be between 275 and 330°F (135 and 166°C). Aggregate should be coated and no visible drain down should occur in storage silos or hauling equipment."

NEW SPECIFICATION !!!!!!!!

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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.

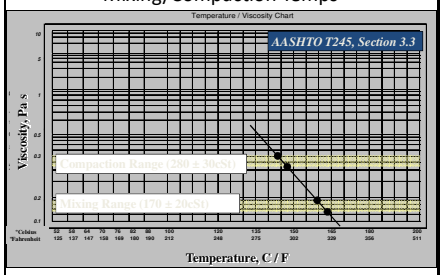
The temperature at which the viscosity is 1.7 ± 0.3 Poise is used to select the mix temperature. The temperature at which the viscosity is 2.8 ± 0.3 Poise is used to select the compaction temperature. Conversions are the most difficult part of this process.

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

The temperature at which the viscosity is 1.7 ± 0.3 Poise is used to select the mix temperature. The temperature at which the viscosity is 2.8 ± 0.3 Poise is used to select the compaction temperature. Conversions are the most difficult part of this process.

Mixing/Compaction Temps



To establish mixing and compaction temperatures for unmodified binders it is necessary to develop a temperature viscosity chart. This can be done by determining the viscosity at two different temperatures - generally 135 C and 165 C. These two viscosities are then plotted on the graph above and a straight line is drawn between the two points.

Modifiers

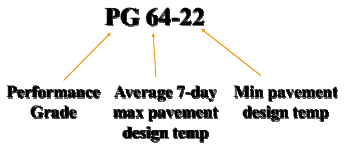
Ref: T.D.O.T. spec. 904.01

If modification of the asphalt is necessary, modification of the asphalt shall be accomplished by properly blending one of the following modifiers:

- Styrene Butadiene (SB)
- Styrene Butadiene Styrene (SBS)
- Styrene Butadiene Rubber (SBR)

PG Asphalt Binder Spec

- Grading System Based on Climate



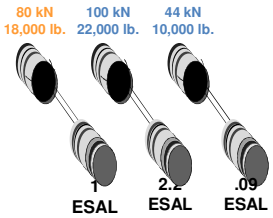
"Rule of 90"

(More like a guideline!)

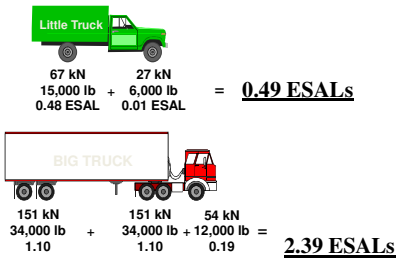
- Balance Between High and Low Temp Physical Properties
  - absolute difference between high and low temp grade
  - Difference < 90 probably unmodified asphalt
  - Difference > 90 probably modified asphalt
- PG 64-22
  - difference = 86
  - probably unmodified
  - probably AC-20
- PG 70-22
  - difference = 92
  - very well balanced AC-20 or lightly modified AC-10

Tennessee uses only elastomeric modification. That is, we specify if asphalt cement is modified, a PG 64-22 must be modified with either an SBS (Styrene Butadiene Styrene), SB (Styrene Butadiene Block Copolymer), or SBR (Styrene Butadiene Rubber, latex) modifier.

ESAL Comparison



The ESAL (equivalent single axle load) concept was developed at the AASHO road test. It is a method of measuring truck volume. It does not compare the actual truck loading, but it compares the damage of differently loaded axles as compared to a standard 18000 lb dual tire axle as shown in the slide.



Notice the relationship is not linear. The axle that weighs 6000 lb contributes 0.01 ESAL while the axle that weighs 12000 lb contributes 0.19 ESAL, while the axle that weighs 15000 lb contributes 0.48 ESAL.

Effect of Traffic Level on Binder Selection

- ESALs < 10 million ~10,000 ADT
  - Use base grade of PG 64-22
- ESALs > 10 million ~ 10,000 ADT
  - "consider" increasing high temp grade by one (PG 70-22)
- ESALs > 30 million ~ Interstates
  - increase high temp grade by one (PG 76-22)

TDOT's policy now is to use PG 64-22 as the base grade of asphalt and that grade shall be used on all routes up to 10000 ADT unless heavy loading situations exist. All non-interstate routes over 10000 ADT shall require a PG 70-22 grade. And PG 76-22 shall be used on Interstate routes or where exceptional heavy loading situations exist.

Aggregate Processing

- Excavation
- Transportation
- Crushing
- Sizing
- Washing

There are five general steps needed to prepare individual stockpiles of aggregates. Once stockpiles have been prepared, two or more stockpiles are typically blended together to produce a final gradation for a given construction application.

Excavation

* Natural sands and gravels
  - Underwater sources
    + Rivers & lakes
    + Barge-mounted dredges, draglines, scoop, conveyors, or pumps
    + Relatively clean
  - Land sources
    + Gravel or sand pits
    + Bucket loader

Excavation of natural sands and gravels from under water sources requires the use of barge-mounted dredges, draglines, scoops, conveyors, or pumps to bring the material above the water line. Sand and gravel pits (land sources) are excavated using back hoes and bucket loaders. The following photos show examples of these procedures.

Natural sands and gravels have a rounded appearance due to the weathering action of water. Rounded natural sands are commonly used in portland cement concrete applications but crushing is required to obtain a more angular shape for use in asphalt concrete.

Excavation

Some aggregate sources are obtained by removing materials from the bottom of lakes and rivers.

Excavation

* Crushed stone and rock
  - Rock depths < 50 ft., overburden washed out during processing
  - Rock depths > 50 ft., remove overburden
    + Soil stripped with bulldozers and scrapers
  - Blasting required

Excavation of rock ledges requires blasting the solid ledges into transportable sizes. However, this can still leave very large blocks of rock to be moved. One or more crushing operations are needed to further reduce the size of the material. As a result of the blasting and crushing operations, quarried aggregates always have an angular particle shape.

The following photographs show examples of these types of operations.

Excavation

This photograph shows typical operations in a limestone quarry.

Crushing

The first step in preparing stockpiles for specific uses is the crushing the larger boulders and aggregates into usable sizes.

Crushing

River Gravel | Partially Crushed River Gravel

Crushing of river gravels is used to change the shape of the aggregate particles.

Sizing

Once the rock has been sufficiently reduced in size, it is separated into individual stockpiles with specific ranges of particle sizes. Large screening operations have a number of wire mesh screen decks with each deck having progressively smaller openings between the wires. These screens are slanted and empty the material retained on each screen out onto conveyor belts. These belts then move the material into individual stockpiles of a particular size.

Stockpiling

* Prevent segregation and contamination
* Good stockpiling = uniform gradations
  - Short drop distances
  - Minimize moving
  - Don't use "single cone" method
  - Separate stockpiles

Poor stockpiling practices can result in particle size separation even within a pile of limited particle sizes. Good stockpiling practices limit the drop distance and prepare a number of small stockpiles for a particular gradation of aggregate. This minimizes the separation of the fine and coarse particles. Moving stockpiles with trucks and dozers should be minimized in order to prevent excessive degradation of the aggregate (that is, more very fine particles). The following photographs show examples of good stockpiling practices.

Stockpiling

This photograph shows a typical stockpiling operation.

Sampling

Why Sampling Is Important

- To evaluate the potential quality of a proposed aggregate source.
  - Does new source meet aggregate specifications?
- To determine compliance with project specification requirements.
  - Do current aggregates meet specifications?

Once stockpiles have been produced, it is necessary to determine the final gradation and aggregate properties of each stockpile. There are specific guidelines which need to be followed in order to obtain samples of aggregates which represent the entire stockpile. Samples can be obtained from the stockpiles themselves or from the conveyor belts which move the aggregate from storage bins into the hot mix asphalt (HMA) plant.

Source Aggregate Properties

- Toughness
- Soundness
- Deleterious Materials
- Gradation

Source aggregate properties are those properties which are measured for the aggregate as-stockpiled and are commonly used for aggregate source acceptance control. These properties are toughness, soundness, and deleterious materials. In addition, the gradations of individual stockpiles may be evaluated.

Toughness

* **Los Angeles Abrasion (AASHTO T96):**
  Resistance of coarse aggregate to abrasion and mechanical degradation during handling, construction and use
* **Aggregate at standard gradation subjected to damage by rolling with prescribed number of steel balls in large drum for a given number of rotations**
* **Result expressed as % changes in original weight**

This test subjects the coarse aggregate (in this case, retained on the 2.36 mm sieve) to impact and grinding by steel spheres. Each sphere has a mass between 390 and 445 g. The number of spheres introduced into the drum depends on the gradation of the aggregate to be tested. The number of spheres increases with increasing size of aggregate.

Once the aggregate and spheres are placed in the steel drum, the machine is rotated at between 30 and 33 rpm's for 500 revolutions. The aggregates are then removed from the drum and sieved to determine the degradation as a percent loss. The percent loss is the difference between the original mass at the required gradation and the final mass of the test sample)

LA Abrasion Test

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

This photo shows the equipment needed for the Los Angeles abrasion test. The panel on the side of the drum is removed and the aggregate and steel balls are placed inside. The panel is replaced and the drum rotated the prescribed number of cycles.

Examples of typical values are noted at the bottom of this photo.

Soundness

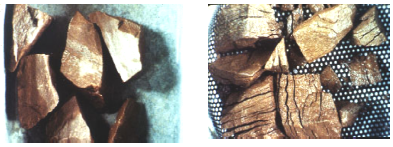
* Estimates resistance to weathering .

* Simulates freeze/thaw action by successively wetting and drying aggregate in sodium sulfate or magnesium sulfate solution
  + One immersion and drying is considered one cycle

* Result is total percent loss over various sieve intervals for a prescribed number of cycles
  + Max. loss values typically range from 10 to 20%per 5 cycles

Weathering of aggregates is simulated by repeated immersion in saturated solutions of either sodium or magnesium sulfate followed by oven drying. The internal expansive force from the expansion of the rehydration of the soluble salts upon re-immersion simulates freeze-thaw damage. The difference between the original and final mass, expressed as a percent of the original mass is the percent loss. A weighted percentage is used when several fractions are tested. The soundness of both fine (passing the 4.75 mm sieve) and coarse aggregate can be determined using this test.

Soundness



Damage to the aggregate after a number of wet-dry cycles can be seen by visual examination as well as in the change in gradation.

Gradations

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

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

For this test (AASHTO T11), a portion of aggregate is dried and the original mass of the sample is recorded. The aggregate is then placed in a bowl, gently washed with water, and the water decanted over a 0.075 sieve. When the water being decanted is reasonably clear, the aggregate is removed container. Any aggregate retained on the sieve used for decanting is returned to this sample and then dried to a constant mass. Once the dry mass is recorded, it is used for the mechanical particle size analysis.

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

In the second step (AASHTO T27), the oven dry aggregate is placed in a stack of increasing smaller sieves, placed in a shaker and agitated for about 5 to 10 minutes. Gently separate the sieves and determine the mass of the sieve and aggregate. Dump aggregate out of sieve, thoroughly clean the sieve, and determine the mass of the sieve without the aggregate.

Mechanical Sieve

Individual Sieve

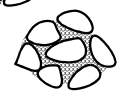
Stack of Sieves

Each sieve has wire mesh in the bottom. The sieve size (4.75 mm, 2.36, mm etc.) denote the distance between each wire. Sieves are stacked from largest openings on the top to smallest openings on the bottom. There is always a pan (no openings) at the bottom of the stack.

Types of Gradations

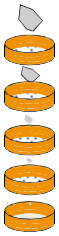
- **Uniformly graded**
  - **Few points of contact**
  - **Poor interlock (shape dependent)**
  - **High permeability**

- **Well graded**
  - **Good interlock**
  - **Low permeability**
- **Gap graded**
  - **Only limited sizes**
  - **Good interlock**
  - **Low permeability**



Aggregate Gradation

- Use 0.45 Power Gradation Chart
- Blend Size Definitions
  - maximum size
  - nominal maximum size
- Gradation Limits
  - control points
  - restricted zone



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

For HMA pavements these are the definitions for gradations.

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)

One sieve above that...

→ The NMAS for this blend is ½ inch.

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

One size above NMAS...

Max. Aggregate Size

Specific Gravity, G

Ratio of the mass to volume of an object to that of water at the same temperature

$$\frac{\dfrac{\text{Mass Solid}}{\text{Volume}}}{\dfrac{\text{Mass Water}}{\text{Volume}}}$$

Densities

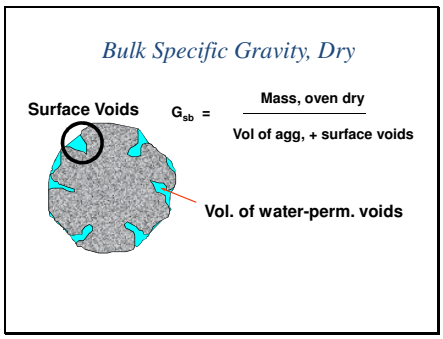
Density is the unit weight of a material
lb/ft^3 or kg/m^3
Unit weight = γ_w G

γ_w = 1.000 g/cm^3 γ_w = 62.4 lb/ft^3

γ_w = 1000 kg/m^3

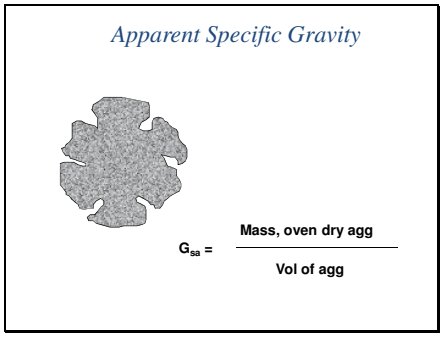
- **Bulk density means sample contains more than one mass and/or volume**

Density is the specific gravity times the unit weight (mass) of water and relates mass to volume: for example, grams per cubic centimeter. Since the unit weight of water in units of 1 g/cm^3, this term is sometimes left out of equations shown in test methods. Care needs to be taken if the units of the test are changed.

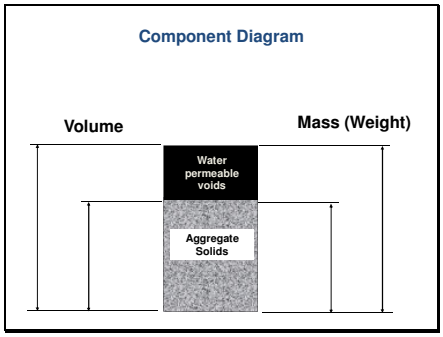


This slide defines the mass and the volume used to calculate the bulk specific gravity (dry) of aggregates.

G designates specific ***g***ravity. The subscripts indicate the material tested (s = stone) and the type of specific gravity (b=bulk). In this case, bulk is used because there is more than one component in the volume.



This slide shows the mass and volume used to determine the apparent specific gravity.



A phase diagram is usually used to represent relationships between mass and volume. The specific gravity of each component in the mixture is needed in order to determine the corresponding volume a given mass occupies

Specific Gravity Tests for Aggregates

- Two tests are needed
  - Coarse aggregate (retained on the 4.75 mm sieve)
  - Fine aggregate (passing the 4.75 mm sieve)

The specific gravities of aggregates need to be determined separately for the fine and coarse fractions of either a stockpile or a blended material.

Consensus Aggregate Properties

Coarse Aggregate Particle Shape
% Crushed Faces
Flat and Elongated
Fine Aggregate Particle Shape
Clay Content

***** Determined for the blended aggregate gradation *****

The consensus aggregate properties of the combined gradation need to be determined once a gradation, or several trial gradations, have been selected.

Percent Crushed Fragments in Gravels

- Quarried materials always 100% crushed
- Minimum values depended upon traffic level and layer (lift)
- Defined as % mass with one or more fractured faces

The appropriate percentages of each aggregate stockpile are combined and then split on the 4.75 mm screen. The material retained on the 4.75 mm screen are used to determine the percent crushed faces

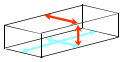
Percent Crushed Fragments in Gravels

0% Crushed **100% with 2 or More Crushed Faces**

This is a measurement of coarse aggregate angularity. The amount of crushing (angularity) is important because it determines the level of internal shear resistance which can be developed in the aggregate structure. Round, uncrushed aggregates tend to "roll" out from under traffic loads and therefore have a low rutting resistance.

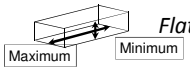
Flat and Elongated Particles

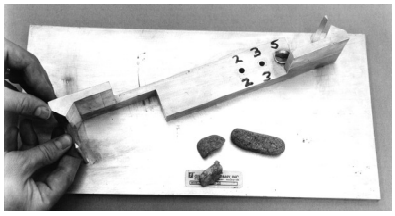
- ASTM D4791
  - Flat
  - Elongated
  - Total flat and elongated
- Superpave
  - Flat and Elongated
  - Maximum to minimum dimension
    - 5:1
    - 3:1
    - 2:1



Flat and elongated particles are undesirable since they have a tendency to break during construction and under traffic. If they do not break, they tend to produce mixtures with directionally-oriented material properties.

Flat and Elongated





The longest dimension of an aggregate particle is used to set one end of the caliber. (pin is at the 5:1 ratio pivot point).

Basic Materials Summary

- Asphalt
  - Hot, Black, and Sticky
  - Correct grade
- Aggregates
  - Angular, with good surface texture
  - Hard and Sound
  - Well Blended with Consistent Gradations

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 Mix – Section 307
  A, AS, ACRL, B, BM, BM2, C, CS, & CW
- Treated Permeable Base – Section 313
  TPB
- Surface Mix – Section 411
  D, E, E(shoulder)

COMMON TDOT PAVEMENT STRUCTURE

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".

SOP 3-4

"Submittal and Approval of HMA Designs"

- Mixes Requiring Design:
  B, BM2, C, CS, CW, D, E, 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.

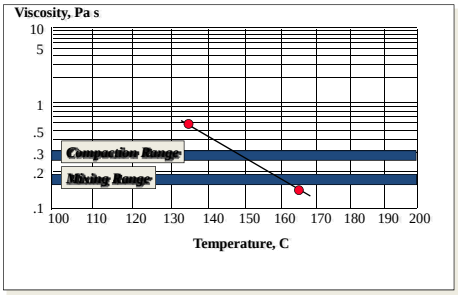
Asphalt Binder

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

Asphalt Binder

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

Temperature-Viscosity Curve



The temperature at which the viscosity is 1.7 $\pm$ 0.3 Poise is used to select the mix temperature. The temperature at which the viscosity is 2.8 $\pm$ 0.3 Poise is used to select the compaction temperature. Conversions are the most difficult part of this process.

Aggregate

- Aggregate
  - Sources to be used, plant to be run out of
  - Sizes available, quantity
  - Stockpile gradations
  - Aggregate source properties
    - Fractured face count, glassy particle determination
    - Specific Gravity (individual stockpile)
    - Soundness, L.A. Abrasion

It is important when beginning a design to have all the supporting information beforehand. Stockpiles available for use, and the corresponding stockpile gradations must be accurate. The material should be known to be of good quality, and if at all possible, experience should be gained by running the material in years past.

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.

  i.e. – "D" Mix cannot have any more than 25% natural sand. (TDOT Spec 411.03)
- 411-D mix has more of these restrictions than any other.
- Why would we be most concerned with D mix?

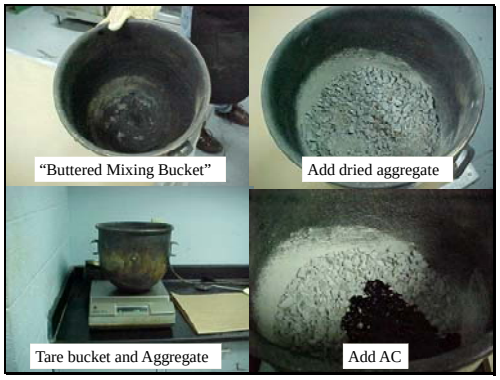
First Steps

- Blend stockpile gradations mathematically to meet the specified gradation (and check it)
- Check blended aggregate properties (G_{sb}, G_{sa}, LOI, etc)
- Estimate Optimum Asphalt Content from TDOT spec and old designs
- Prepare mix samples at four or more AC contents around the estimated optimum asphalt content
  - *"2 ABOVE OPTIMUM AND 2 BELOW.." (TDOT Spec – 407.03 (C) 1.*

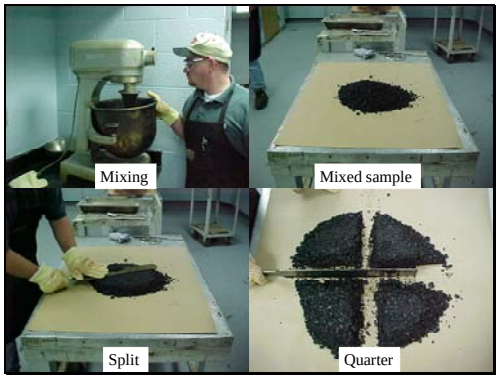
As a designer, you should know what materials you have to work with, such as available aggregates, AC, anti-strip additives, etc. A designer that is very familiar with his materials is likely to build a better design. This means knowing the gradation, specific gravities, and variability of his aggregates, which is a knowledge best obtained by running stockpile gradations as often as reasonably possible.

Blending Stockpiles

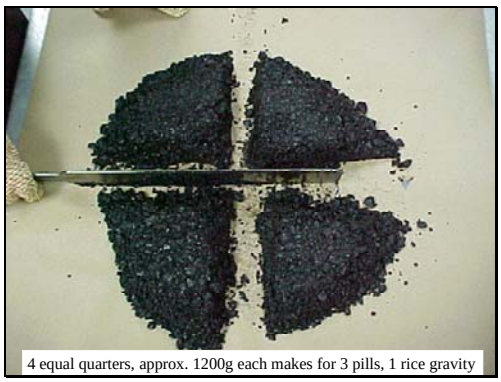
- P = Aa + Bb + Cc + ….
  - Where:
    - P = % of material passing a given sieve for the blended aggregates A, B, C, …
    - A, B, C, … = % material passing a given sieve for each aggregate A, B, C, …..
    - a, b, c, …. = Proportions (decimal fractions) of aggregates A, B, C, … to be used in blend



"Butter"the mixing bowl by mixing a sample with AC and discarding that sample. Place blended, heated, aggregate in heated mixing bowl and form a depression to hold AC. Tare bowl and aggregate add appropriate amount of AC . Mixing temperatures are determined from the AC supplier's temperature/viscosity chart (sec. 3.4).



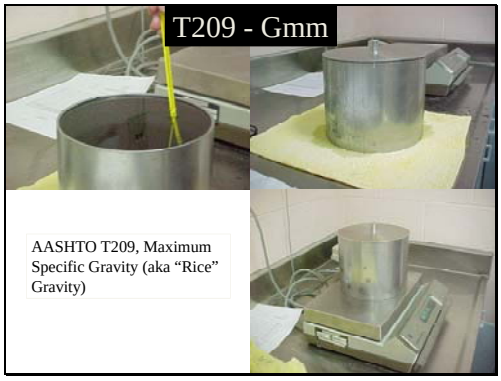
If more than one 1200g samples are mixed at the same time, then the entire mixed sample must be reduced in accordance with AASHTO T-248 (standard method for splitting and quartering).



Next Steps

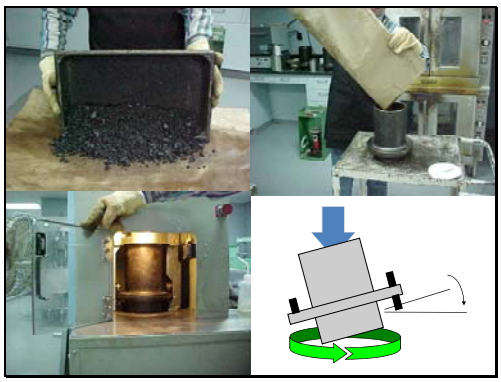
- Age the Gmm samples and perform Rice Gravity tests (T209)
- Compact the Samples after compaction temperature is reached
  - 75 blows per side — Conventional Mixes
  - Ndes — Superpave Mixes
- Extrude from the molds
- Allow the samples to cool

At least three of the rice gravity samples should have the test performed on them. Samples should be aged (at compaction temperature) for approximately 2 hours prior to compaction to simulate the aging that occurs in silos, on trucks, etc.



As the Rice gravity results are calculated, calculate the effective aggregate gravity for each test and average them. Then use the average effective gravity to calculate Rice gravities for the mix design AC contents. Hopefully, this will make the design curves look more normal and will give a good approximation of the Rice gravity at Optimum AC content.

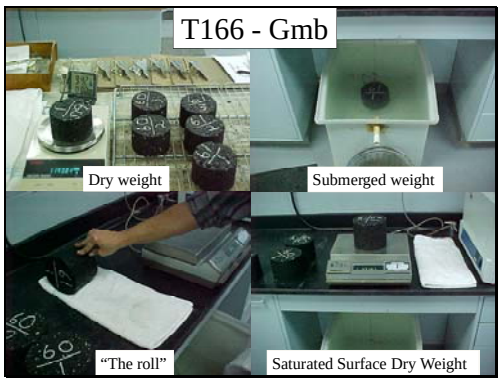
Compact specimens the desired number of blows(usually 75 blows per side). Tennessee requires compaction equipment to be a mechanical hammer with rotating base and slanted foot. Remove the mold collar and base plate and extrude specimen taking care to avoid deforming the surface texture. Allow specimens to cool to room temperature (sec 3.5.2). After cooling, AASHTO T-166 should be performed to determine volumetric properties of the samples.



Procedures are similar for Superpave sample compaction. These ~4600 gm samples are aged and then the whole sample is loaded into the compactor mold and compacted to Ndes. Upon completion of compaction, the samples are extruded and allowed to cool. Because of their size, these samples may take longer to cool than 1200 gm Marshall samples.

Next Steps

- Perform Bulk Gravity tests on samples (T-166)
- Calculate Volumetric Properties
  - Va
  - Voids in Mineral Aggregate (VMA)
  - Voids Filled with Asphalt (VFA)
- Measure Stability and Flow



Prepare test specimens in accordance with AASHTO T-245 (or TP-4 for Superpave). Measure mass of specimen (dry) in air. Then submerge specimen in 77° F +/- 1.8° F (25°C +/- 1° C) water for 4 +/- 1 minutes. Record the immersed mass. Remove specimen from water and quickly blot specimen dry with damp towel. Record mass of specimen at SSD condition(sec. 4).

Calculate Volumetric Properties

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

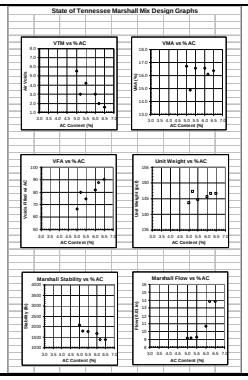
$$V_a = 100 \times \frac{G_{mm} - G_{mb}}{G_{mm}}$$

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

Immerse compacted specimens in 140°F +/- 1.8°F water bath. After 30 - 40 minutes, remove specimens and test stability and flow in accordance with section 4.1. **Note**:the elapsed time for the test from the removal of the test specimen from the water bath to the maximum load determination shall not exceed 30 seconds (sec.4.2)

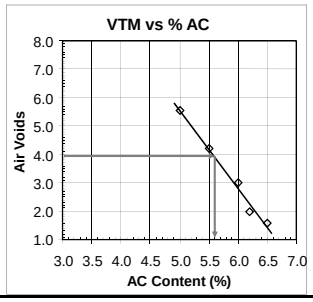
Almost Finished

- Plot curves
- Select Optimum AC
- Check other Criteria
- Complete Paperwork
- Calibrate NCAT Furnace



Plot the corresponding data against the AC content to examine the mix design graphs and to determine if the mixture meets specifications. General trend information for each graph can be found in the formula/abbreviation section of the workbook.

Select Optimum AC



Tennessee recommends selecting the AC content where 4% air voids is achieved as optimum AC content. After optimum AC content is selected, the mixture should be checked for sensitivity in both air voids and VMA. See the standard specs. Notice this design has the necessary 2 point above optimum and 2 points below. Anything less may give us a chart that could lead to selecting the incorrect optimum AC.

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))

Complete Paperwork

- Excel Mix Design File
  - Required 2002
  - Requested 2001
- Check Design Sheet Information
- Summary Report
- Signature, Cert Number

Make sure all project numbers are entered in the required locations, as well as the letting date so that proper specifications can be applied. When submitting designs, make sure to use the most up-to-date version of the JMF Workbook, available at http://www.tdot.state.tn.us/materials/fieldops/bituminous.htm . Mix designs turned in on old versions of the workbook will be turned away.

AGGREGATES

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- AASHTO T248 – Reducing Samples of Aggregate to Testing Size
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- AASHTO T27 – Sieve Analysis of Fine and Coarse Aggregates

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- Combined Specific Gravity
- RAP Calculations
- AC Calculations

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- AASHTO T84 – Specific Gravity and Absorption of Fine Aggregate
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- TDOT Test for Loss On Ignition (LOI)
- TDOT Test for Glassy Particles
- Fractured Faces (by count)
- ASTM D4791 – Flat Particles, Elongated Particles

POWER 45 CHARTS..... 44

AASHTO T-2

Standard Practice for Sampling Aggregates

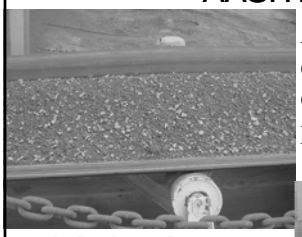
AASHTO T-2

- Determine NMAS
- Go to TABLE 1 in spec.
- Determine sample size

TABLE 1 Size of Samples

Maximum Nominal Size of Aggregates	Approx. Minimum Mass of Field Samples lb (kg)
Fine Aggregate	
No. 8 (2.36mm)	25 (10)
No 4 (4.75mm)	25 (10)
Coarse Aggregate	
3/8 in. (9.5mm)	25 (10)
1/2 in. (12.5mm)	35 (15)
3/4 in. (19.0mm)	55 (25)
1 in. (25.0 mm)	110 (50)
1.5 in. (37.5mm)	165 (75)
2 in. (50 mm)	220 (100)
2.5 in. (63 mm)	275 (125)
3 in. (75 mm)	330 (150)
3.5 in. (90 mm)	385 (175)

AASHTO T-2



AASHTO recommends obtaining belt samples of aggregates whenever possible.

A belt-shaped template must be used. →

AASHTO T-2

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

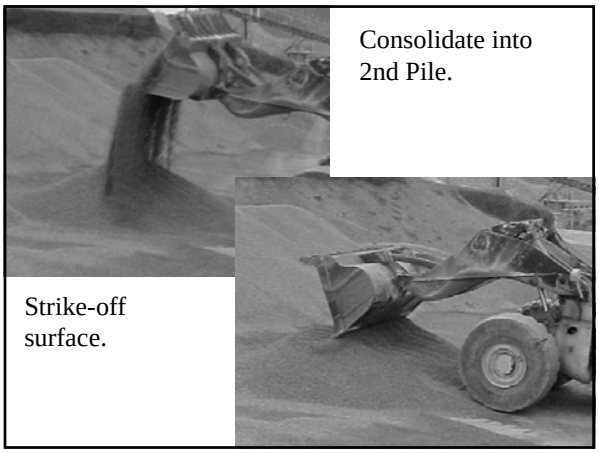
Make sure to sweep all of the fine aggregate off the belt.

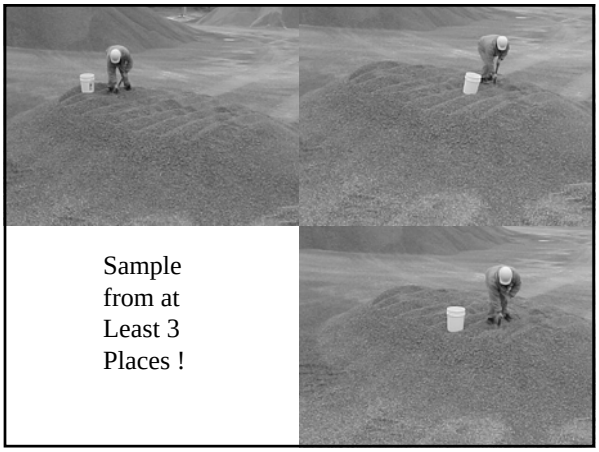
AASHTO T-2

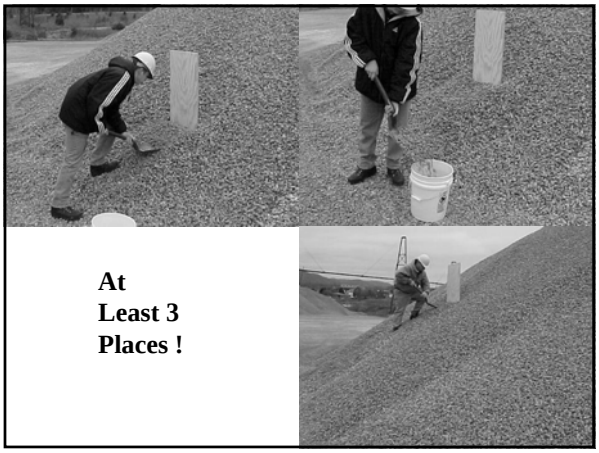
Most raw materials must be sampled from a stockpile instead.

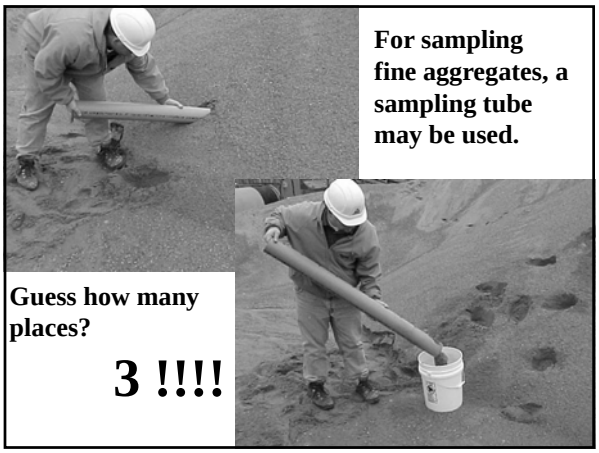
Use power equipment whenever available.

Go into pile in at least 3 different locations.


Consolidate into
2nd Pile.
Strike-off
surface.


Sample
from at
Least 3
Places !


At
Least 3
Places !



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)

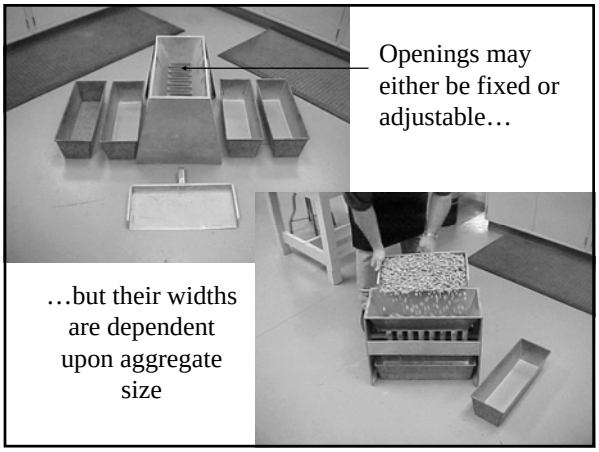
Do we have to test all of the material we sampled!?...

AASHTO T-248

Reducing Samples of Aggregate to Testing Size

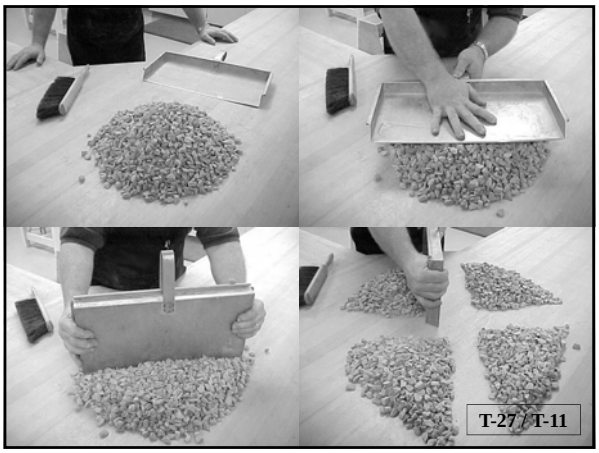
AASHTO T-248

Method A: Using A Mechanical Splitter



AASHTO T-248

Method B: Splitting and Quartering



AASHTO T-11

Materials Finer Than 75 - µm (No. 200) Sieve in Mineral Aggregates by Washing

&

AASHTO T - 27

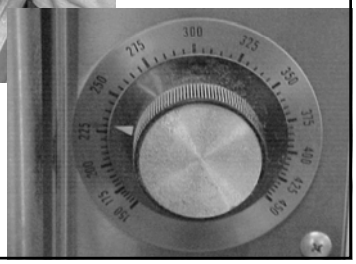
Sieve Analysis of Fine and Coarse Aggregates

Add water and stir gently.

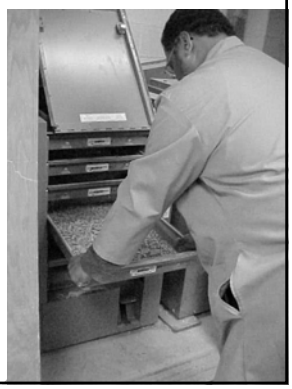
Then carefully decant liquid over a nest of sieves.

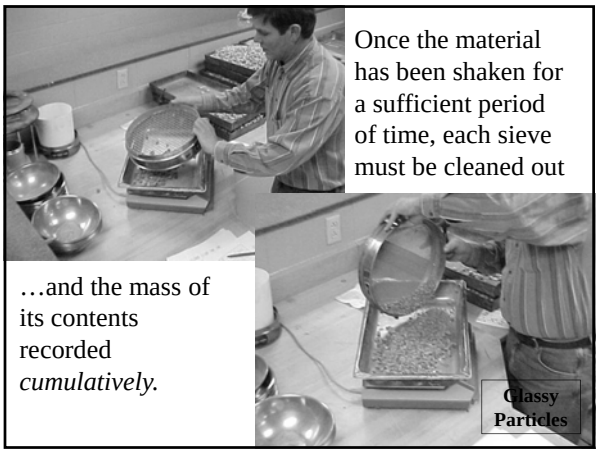
Why a nest?

Continue washing until the liquid is reasonably clear.



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




Once the material has been shaken for a sufficient period of time, each sieve must be cleaned out
…and the mass of its contents recorded *cumulatively.*
Glassy Particles

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

T-27 RESULTS				
U.S. STANDARDS SIEVES	WEIGHT RETAINED	PERCENT RETAINED	PERCENT PASSING	JMF OR SPECIFICATION
2"				
1 1/2"				
1 1/4"				
1"				
3/4"				
5/8"	0.0			
1/2"	0.0			
3/8"	95.7			
NO. 4	345.6			
NO. 8	801.6			
NO. 16	1008.2			
NO. 30	1558.1			
NO. 50	1703.0			
NO. 100	1801.3			
NO. 200	1859.8			
PAN	1891.2			

Material Passing #200 Sieve

T-11

ORIGINAL DRY SAMPLE WEIGHT (A) 2000.0 grams
WEIGHT OF SAMPLE AFTER WASH (B) 1900.0 grams
WASH LOSS (A-B) _____ grams

T-27

PAN WEIGHT (C) 1891.2 grams
Add'l -#200 Material (C-weight retained #200) _____ grams

Total Material Passing #200 Sieve _____ grams

CLASSROOM EXAMPLES

Turn in your books to "Classroom Examples" for Monday so we can work one of these together...

AGGREGATE PROPORTIONING (AKA – Batching)

TDOT
MATERIALS & TESTS DIVISION

Blending of Aggregates

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

TDOT
MATERIALS & TESTS DIVISION

Blending of Aggregates

- Numerical Method
  - Trial and Error
  - Basic Formula

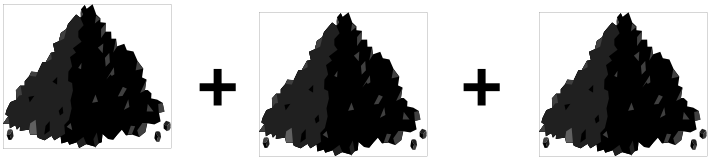
TDOT
MATERIALS & TESTS DIVISION

Blending of Aggregates

- **P = Aa + Bb + Cc + ….**
  - **Where:**
    - **P = % 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 (decimal fractions) of aggregates A, B, C, … to be used in blend**

TDOT
MATERIALS & TESTS DIVISION

Specific Gravity of Aggregate Blend



TDOT
MATERIALS & TESTS DIVISION

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

TDOT
MATERIALS & TESTS DIVISION

- Example Problem -

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

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:

$P_A = 50\%$	$G_A = 2.695$
$P_B = 25\%$	$G_B = 2.711$
$P_C = 25\%$	$G_C = 2.721$

G_{sb} =

TDOT
MATERIALS & TESTS DIVISION

Classroom Problem

TDOT
MATERIALS & TESTS DIVISION

- Classroom Problem -

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

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

Based on the information given:

$P_A = 40\%$ $G_A = 2.695$
$P_B = 30\%$ $G_B = 2.809$
$P_C = 30\%$ $G_C = 2.375$

TDOT
MATERIALS & TESTS DIVISION

Batching and Building Pans

TDOT
MATERIALS & TESTS DIVISION

Batching of Aggregate Blends

- Why Batch
  - We Want To Reproduce the Desired Gradation for Mix Design
  - We can't fire the plant up to make 10 lb

TDOT
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Batching

- Things We Need To Know To Batch
  - % of Each Stockpile in Blend
  - % Retained For Each Sieve of Each Stockpile
- Confidence in gradations is paramount
  - Run lots of them yourself
  - Include manufacturer's quality control numbers

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Batching – Method 1

Mass for Batch per Sieve = % Retained per Sieve * % Stockpile * Batch Wt.

EX:

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

<u>Given:</u>

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

Mass of #4 material =

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Batching – Method 2

Mass for Batch per Sieve = % Retained per Sieve * Individual portion.

EX:

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

<u>Given:</u>

% Retained on #4 sieve = 23.0 %
% Agg. #1 Used in Blend = 30.0 %
Total Batch wt. = 4000 grams
individual portion = .3 *4000 = 1200 grams

Mass of #4 material =

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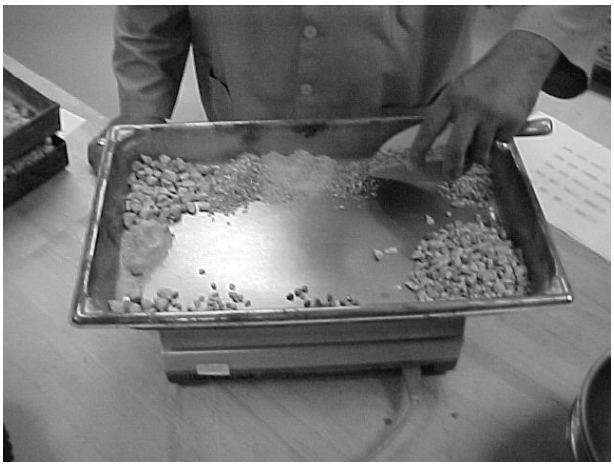
Build it according to your recipe



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Blending of Recycled Asphalt Pavement (RAP) in HMA

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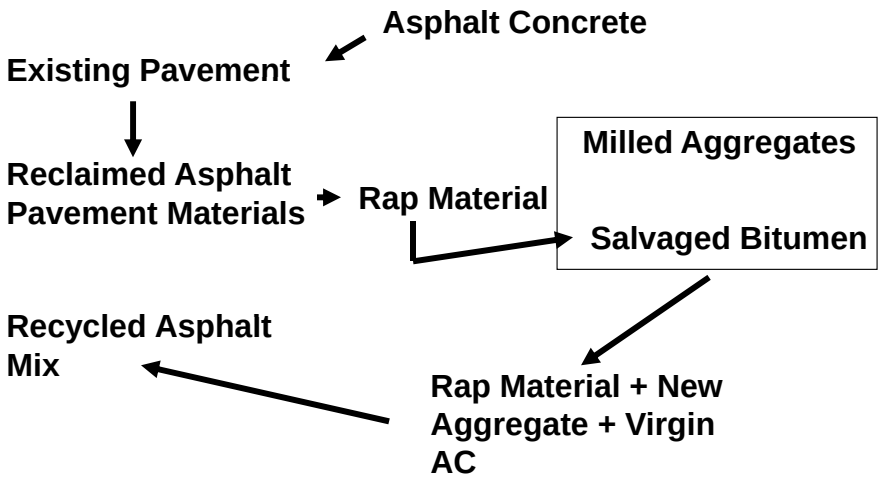
Recycled Asphalt Mix



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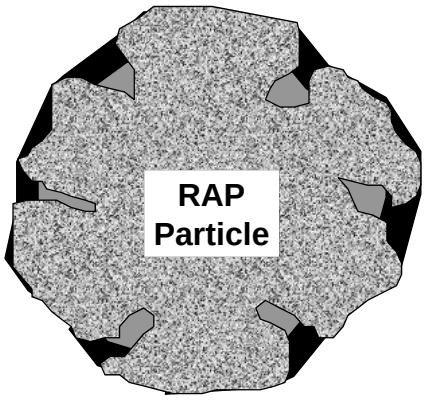
RAP Aggregates and RAP AC



- Black Rock

Or

- Combination of Aged Asphalt and Aggregate

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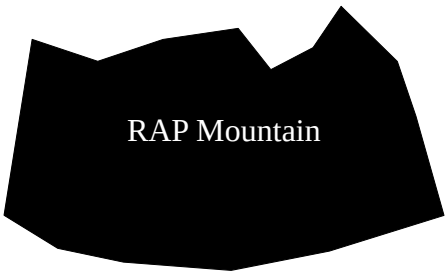
Preparing to use RAP

- Shown to be consistent
  - At least 5 samples
  - Consistent AC content
  - Consistent Gradation
- Known location
- "God Only Knows" Pile



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Abbreviations

- M_{RAP}= Mass of RAP Material
- P_{RAP}= **<u>Decimal</u>** Percentage of RAP in Mix
- M_{TOT}= Total Mass of Aggregates in Mix
- P_{bRap}= Percent AC in RAP
- M_{ACPb}= Mass of Virgin AC

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Rap Blending Calculations

$$M_{Rap} = \frac{P_{RAP} \times M_{Tot}}{\frac{100 - P_{bRAP}}{100}}$$

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Adding Asphalt to the Blend to make HMA mixtures of known AC Content

$$M_{ACPb} = \underbrace{\frac{M_{Tot}}{\left(\frac{100 - P_b}{100}\right)}}_{\text{Total Blend Weight after AC added (asphalt and aggregate}} - \underbrace{\frac{M_{RAP} \times P_{bRAP}}{100}}_{\text{Subtract RAP's AC Contribution}} - \underbrace{M_{Tot}}_{\text{Agg. Wt}}$$

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AC Blending Problem 1

- Aggregate Blend of 4400 gms. No RAP.
- Calculate AC necessary to make blends with AC content of:
  - 4.5%
  - 5.0%
  - 5.5%
  - 6.0%

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AC Blending Problem 2

Material	# 67	78 - M	W. Scrg	RAP	Blend
Percent	10%	45%	35%	10%	100%
1 inch	100	100	100	100	100.0
3/4 inch	97	100	100	100	99.7
1/2 inch	48	100	100	100	94.8
3/8 inch	22	80	100	100	83.2
No. 4	6	21	94	88	51.8
No. 8	4	5	70	67	33.9
Minus 8					
Batch Weight = 4400 grams			RAP AC =	6%	

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Calculate Mass of RAP to Add

M_{Rap} =

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Calculate amount of AC to Add

$M_{AC\,Pb}$ =

=

=

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QUESTIONS ?

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IN CLASS EXAMPLES

Turn in your book to the “Examples” Section so we can do one of these together.

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AASHTO T-84

Specific Gravity and Absorption of Fine Aggregate

- Sieve blend through #4 sieve

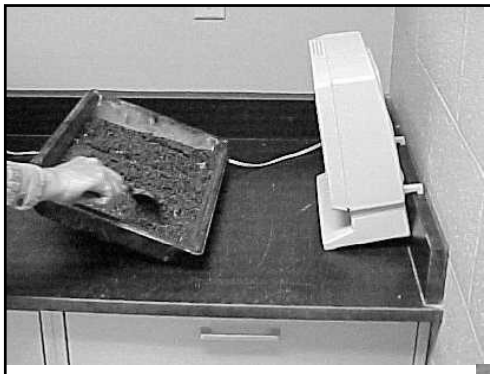
- Separate +4 & -4 material
- Use -4 material

• Place –4 material in individual pan

• Cover material completely with water

• Allow to soak for 15 – 19 hours

• Decant the water after soaking

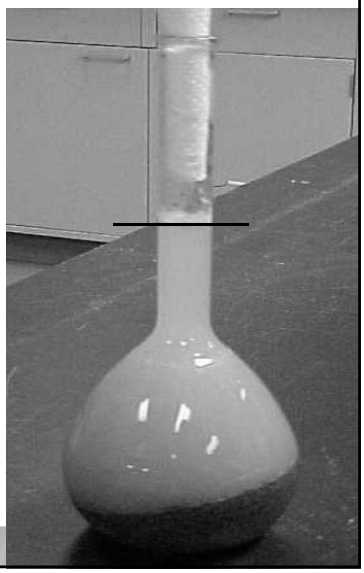


• Partial dry under gently moving warm air
•Stir frequently
• **Do Not** over dry

• Initial cone test w/full moisture
• 25 tamps from 5mm/.2”
• Continue cone test until saturated surface dried (SSD)

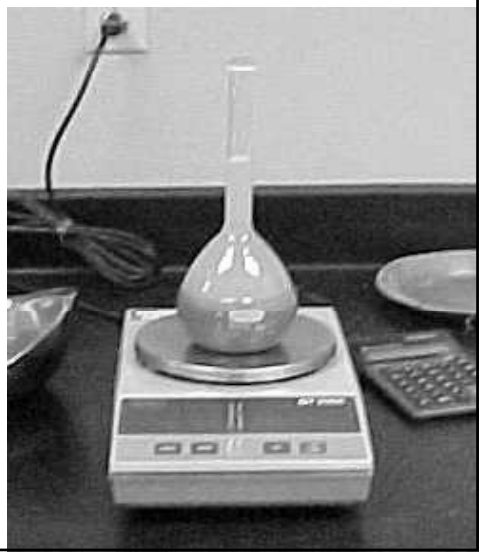
• Initial cone test should stand
• An **OVER DRIED** condition will fall apart
• SSD condition only needs small portion to fall

• Charge pycnometer w/500 ± 10g of aggregate
• Fill pycometer to 90% w/de-ionized water



• Agitate/roll to remove entrapped air from aggregate
• Fill to calibration line and remove air bubbles

• Alcohol may be used to assist in removal of foam



• Record mass of flask-aggregate-water

- Remove aggregate from flask
- Dry to a constant mass
- Record dry mass of aggregate

OR

- You may obtain a second portion of the SSD sample, within 0.2g of the original, to use for dry mass

AASHTO T-85

Specific Gravity and Absorption of Coarse Aggregate

Sieve blend through #4 sieve

- Separate +4 & -4 material
- Use +4 material

- Wash the +4 material

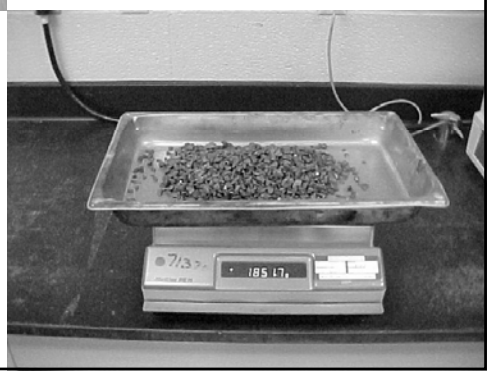
- Completely cover aggregate with water
- Allow to soak 15 – 19 hours

• Decant the water after soaking

• Empty aggregate onto clean dry towel

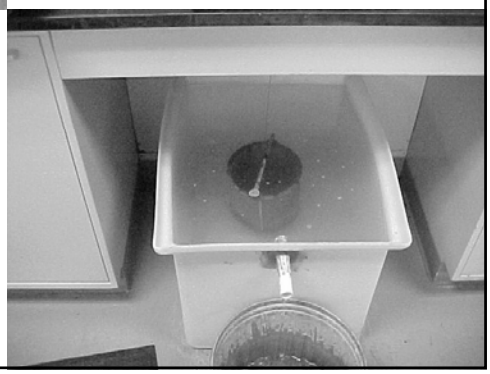
• Towel dry aggregate to remove the wet sheen from outer surface - (SSD condition)

• Tare pan – Record mass of SSD material



• Tare basket – Place **all** material into the basket

• Place basket w/material into tank, shake a few times
• Hang basket and record mass of submerged material



• Remove aggregate from basket and place into pan
• Be sure to ****Remove all aggregate*! ****

• Oven dry to constant mass

TDOT Test for Loss On Ignition (LOI)

Detailed in TDOT Specifications 407.03 (E)

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!!!!**

L. O. I.

Test for Percent loss on ignition of the Mineral Aggregate in a 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.

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.

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.

At what temperature do we burn the aggregate?

1742º F (950º C)

How long do we burn the aggregate? *Min of 8 Hrs.*

Notice how white the aggregate now appears.

Finally, again record the mass of all of the containers filled with the ignited aggregate.

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

L. O. I.
(Calculations)

- Form found in workbook.
- Now we need to calculate our L.O.I. pay factor.

TDOT Test for Glassy Particles

Referenced in TDOT Specifications section 903.11.a.4 (crushed slag)

When slag is used as a coarse aggregate, a check for glassy particles must be performed (on a sample of the + #4 material).

IAW TDOT 903.11.1.4, the slag can't have more than 20% glassy particles as determined by *mass*.

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 = _____ **%**

Calculation Example :

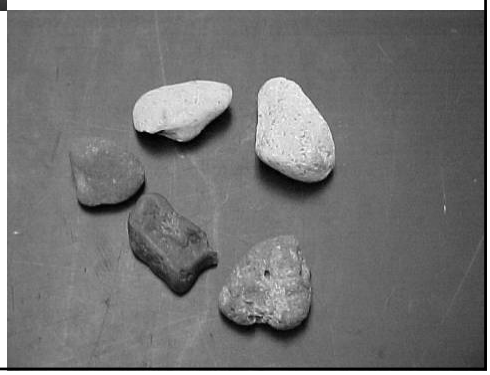
Glassy Particle Test

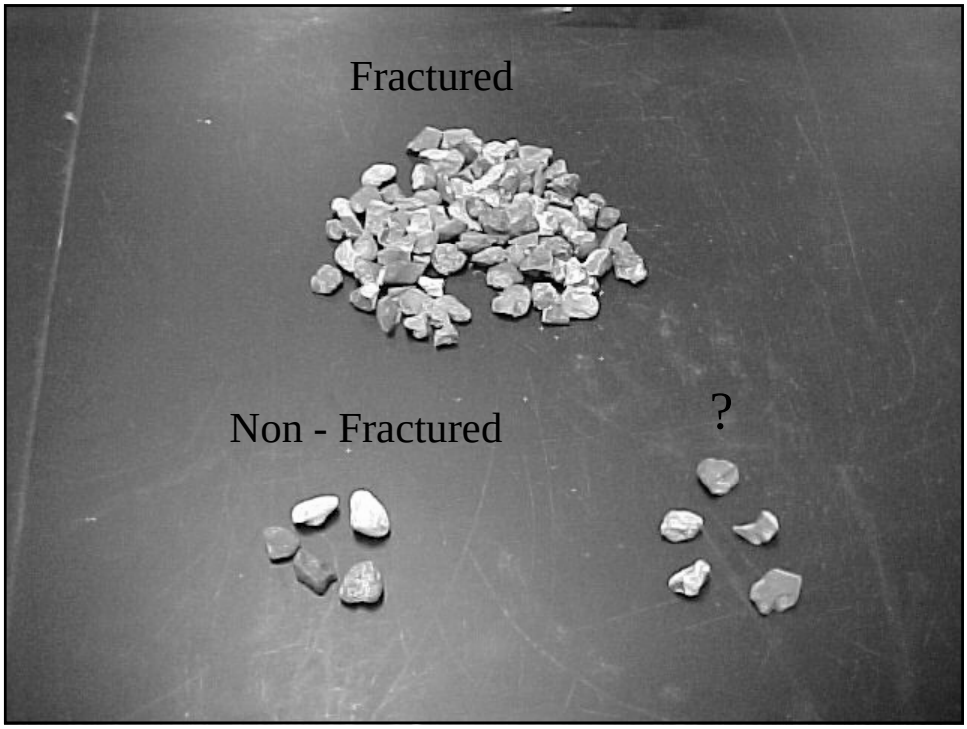
Fractured Face (by count)

Referenced in TDOT Specification sections 903.06.a , 903.11.a.3

When gravel is used as a coarse aggregate, some of the material is crushed, leaving one or more fractured faces. Some particles, however, will not be affected by this process.

We need to determine the % of particles with 2 or more fractured faces by *count* (not by mass).





Calculation Example :

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.

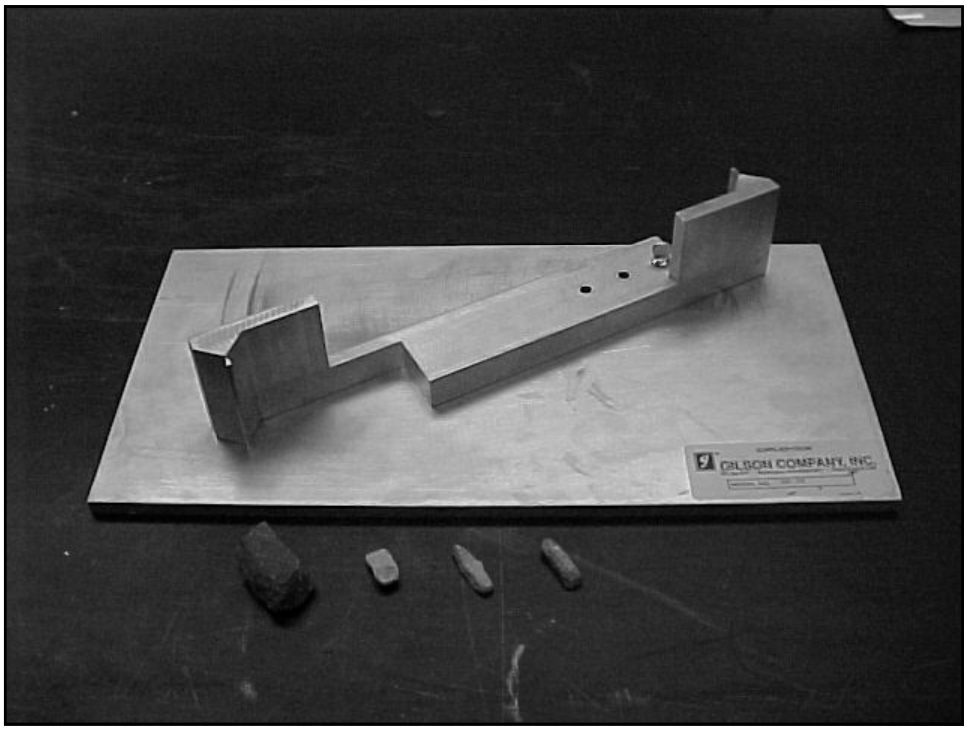
$$\% \text{ Fractured} = \frac{\text{No. of Particles Fractured}}{\text{Total No. of Particles Inspected}} \times 100$$

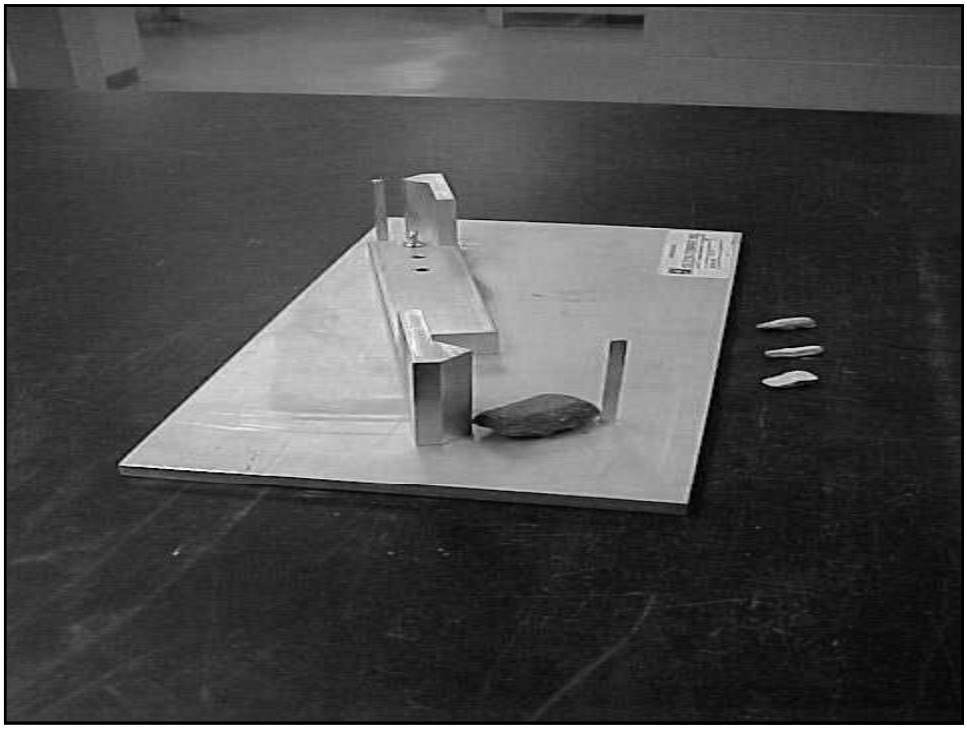
No. of Particles Fractured _____
Total No. of Particles Inspected _____

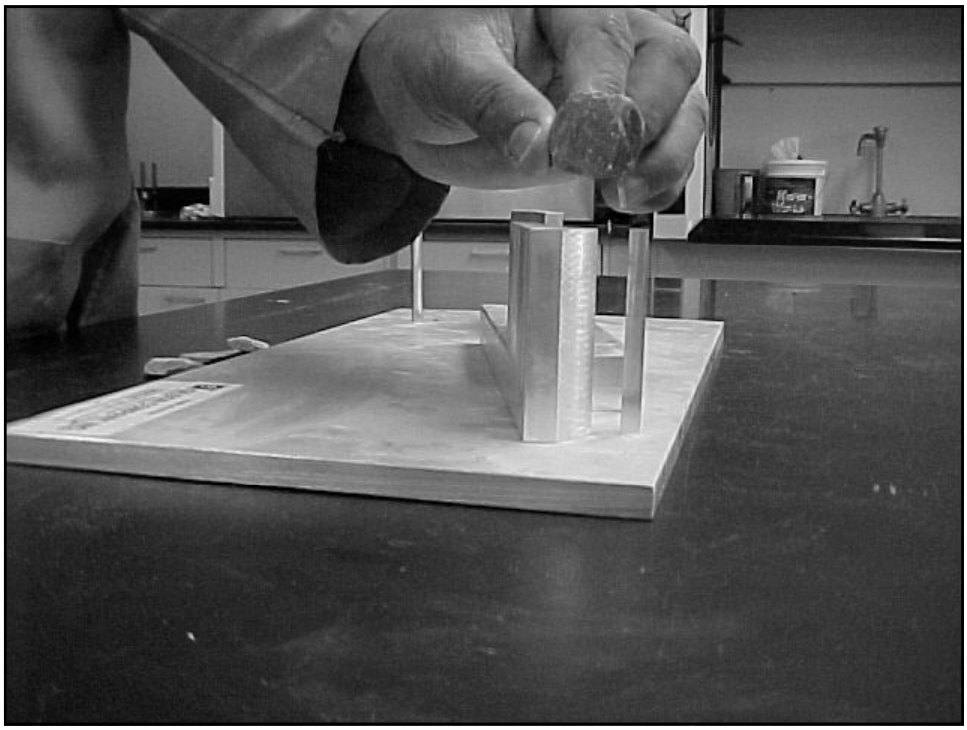
% Fractured = _____ **%**

ASTM D-4791

Flat and Elongated Particles





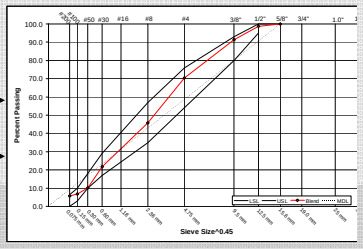


NEXT

- After the break, we will enter the lab for a demo and return to learn how to do these calculations.

Power 45 Charts

Sieve (in)	% Pass
2"	100
1.5"	100
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



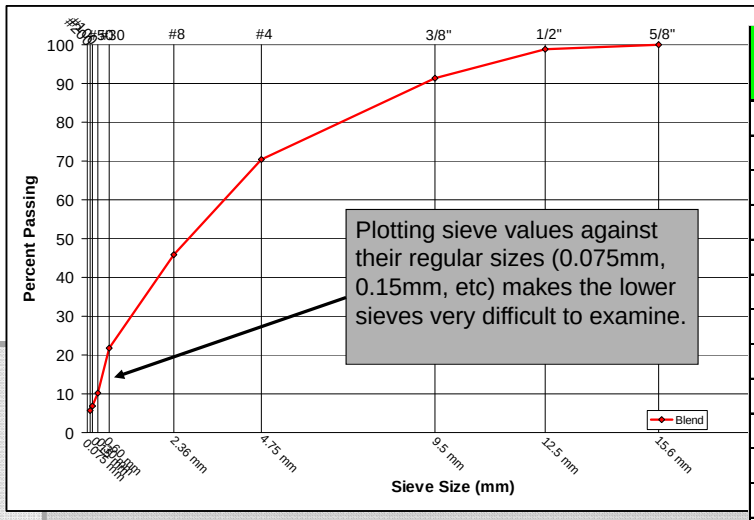
Power 45 Charts

- 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

Why to the 45 Power?

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

Why to the 45 Power?



Sieve (in)	% Pass
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1"	100
3/4"	100
5/8"	100
1/2"	99
3/8"	91
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No.8	46
No.16	
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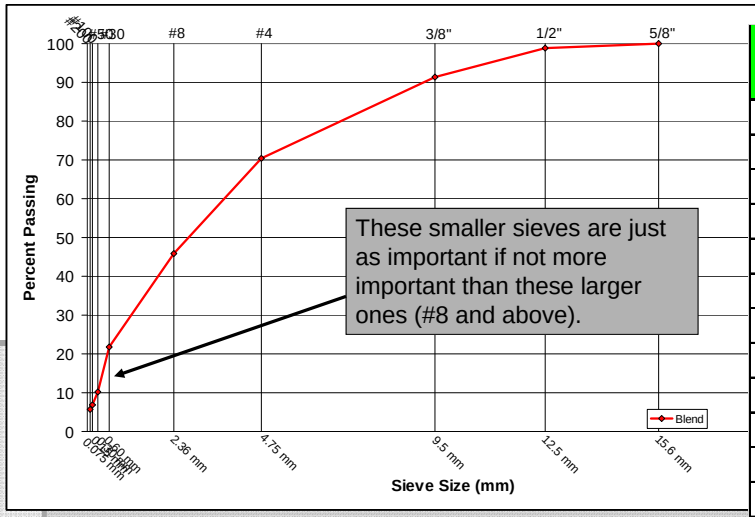

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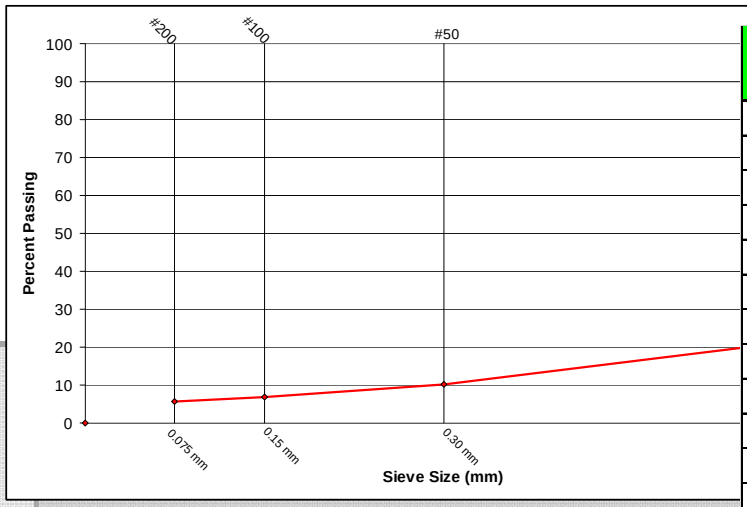

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1"	100
3/4"	100
5/8"	100
1/2"	99
3/8"	91
No.4	70
No.8	46
No.16	
No.30	22
No.50	10
No.100	7
No.200	6

Why to the 45 Power?

- Let's try taking the same blend and raising the sieve values (in millimeters) to the 0.45 power:

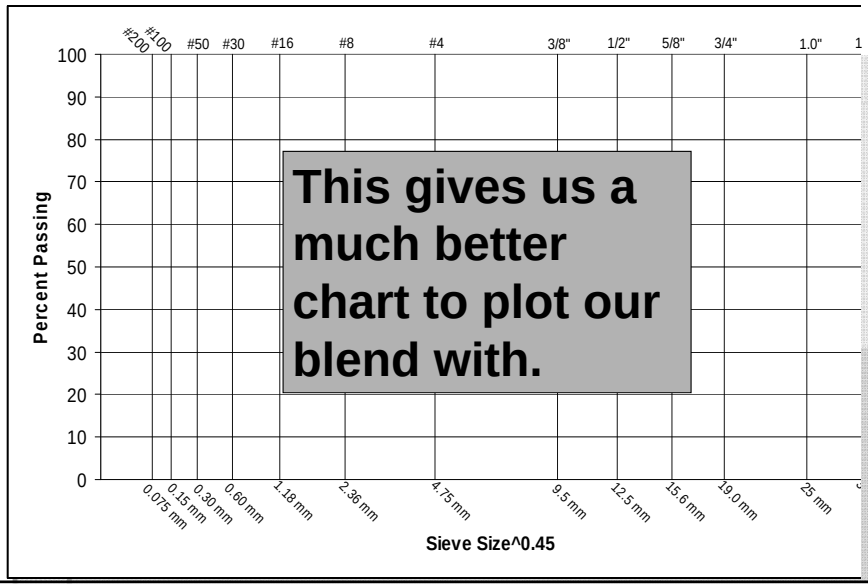
  For example – the #8 sieve, a.k.a. 2.36 mm, raised to the 0.45 equals:

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

Why to the 45 Power?

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

Why to the 45 Power?

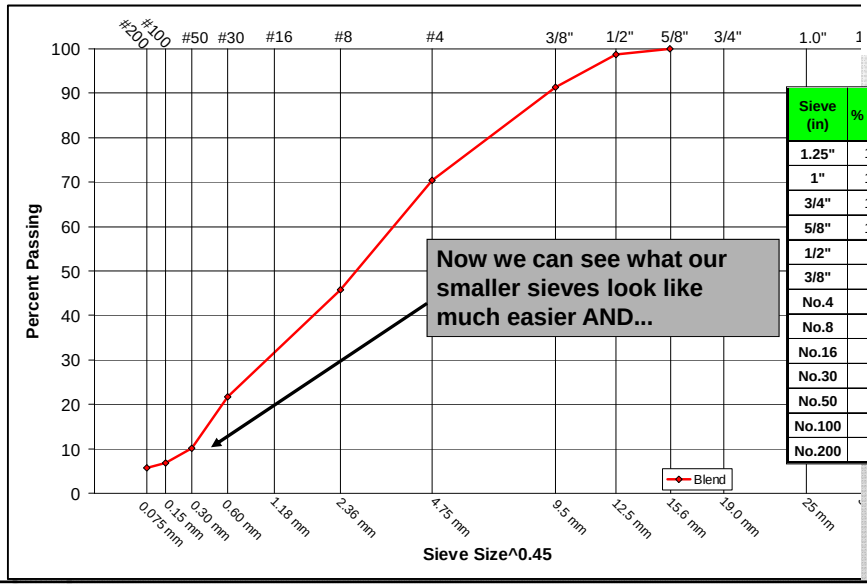


This gives us a much better chart to plot our blend with.

Why to the 45 Power?

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

Why to the 45 Power?



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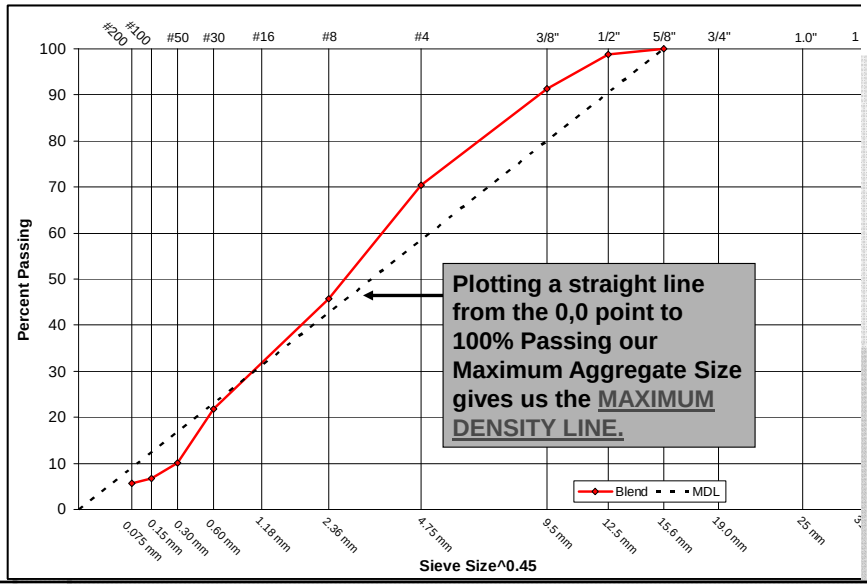
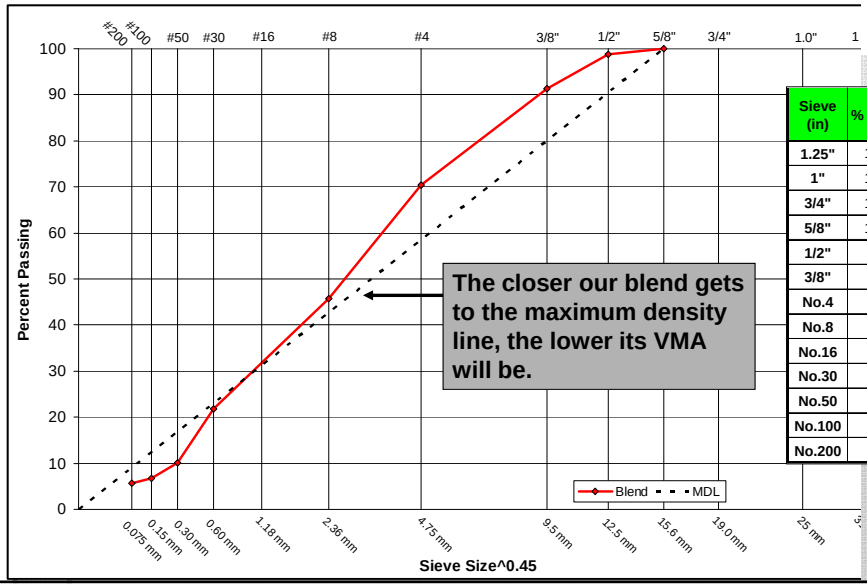


Why to the 45 Power?



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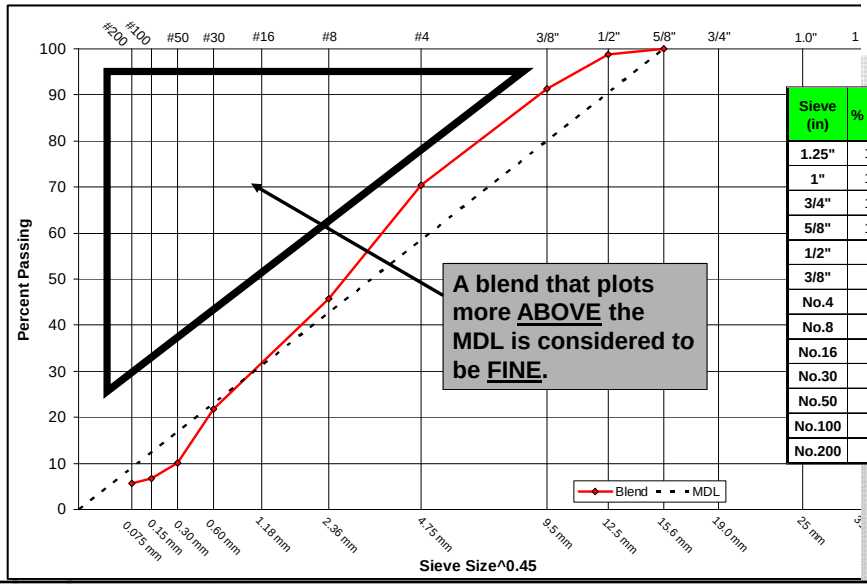

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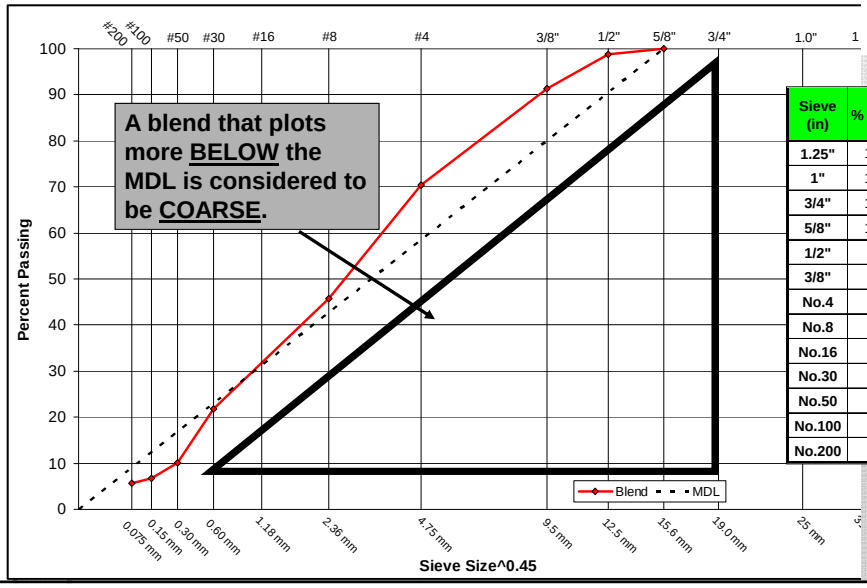
Why to the 45 Power?



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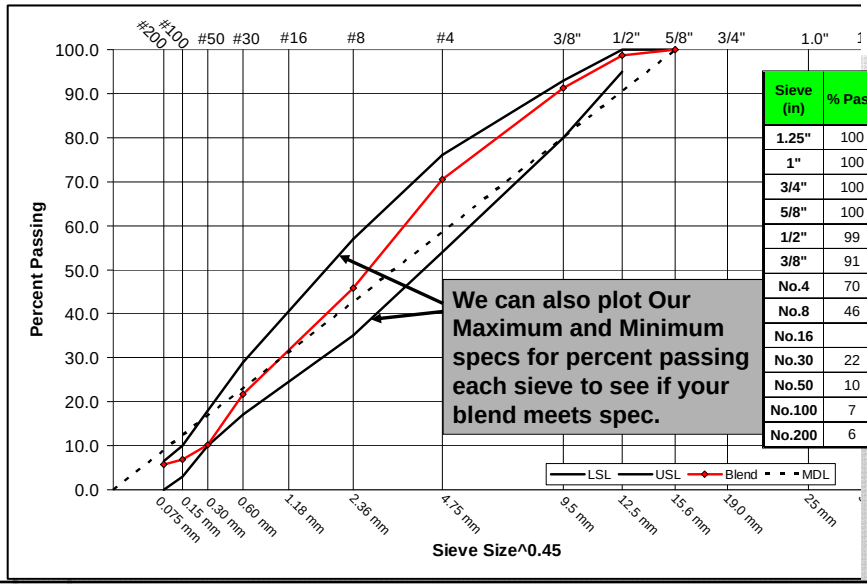
Why to the 45 Power?



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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

Dust / Asphalt Ratio

- Most TDOT mixes have specification ranges for Dust to Asphalt Ratio (DAR)
- DAR = $\frac{\text{(\%Passing \#200 sieve)}}{\text{(\% Asphalt Content)}}$
- Why is this ratio important?

Dust / Asphalt Ratio

- EXAMPLE:

  For the mix we plotted a minute ago, the %Passing #200 was 6%. Let's say the Optimum asphalt content for this design was 5.3%. What's the DAR?

TESTING MIX

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- AASHTO T312 – Preparing and Determining Density of HMA Specimens by Means of Gyratory Compactor

AASHTO T-166

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

AASHTO T-166

Bulk Specific Gravity =

$$Gmb = \frac{\text{Dry Mass of specimen}}{(\text{SSD Mass}) - (\text{Submerged Mass})}$$

Gmb Example

- A Marshall pill weighs:
  - 1214.7 g dry
  - 712.1 g Under Water
  - 1215.9 g After Blotting Dry (SSD)

➔What's the bulk gravity?

$$\frac{\text{Dry}}{(\text{SSD} - \text{Submerged})} =$$

AASHTO T-209

Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures

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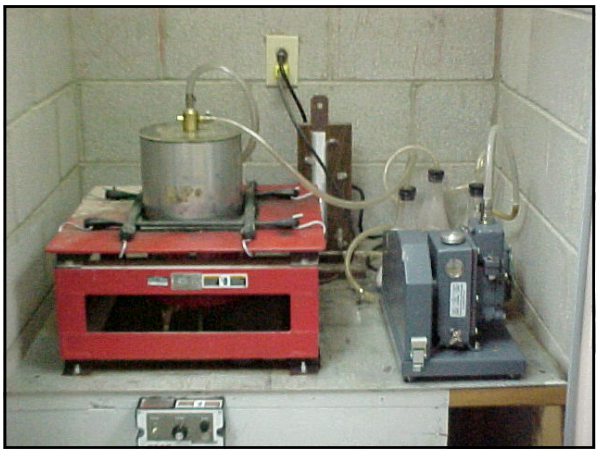

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T-312

AASHTO T-209

Maximum Specific Gravity =

Gmm = 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

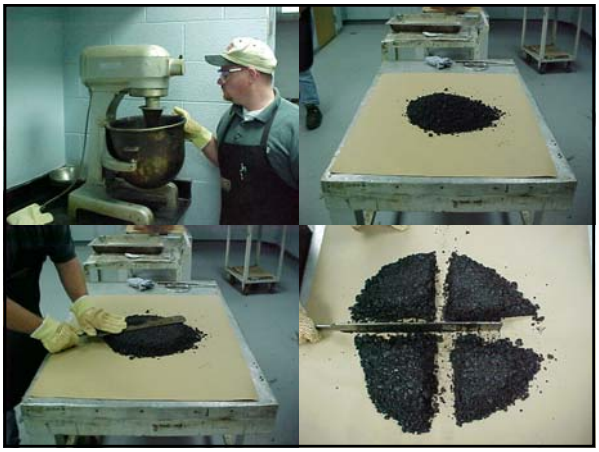
Gmm Example

- Some loose mix weighs ~~4243.1~~ 2234.0 g dry.
- The Pycnometer filled with water weighs 7246.3 g.
- The pycnometer filled with water AND sample weighs 8595.7 g.

➔What's the Rice gravity?

AASHTO T-245

Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus



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

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

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

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
$P_{mm} - P_b / (P_{mm} / G_{mm} - P_b / G_b) = G_{se}$

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

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

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

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))

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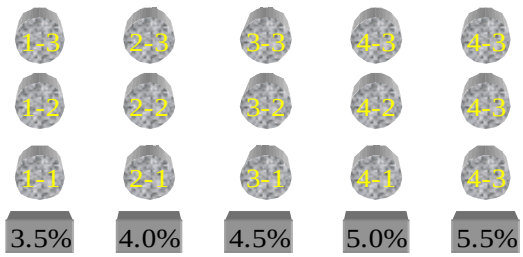
Volumetrics of Compacted Mixture



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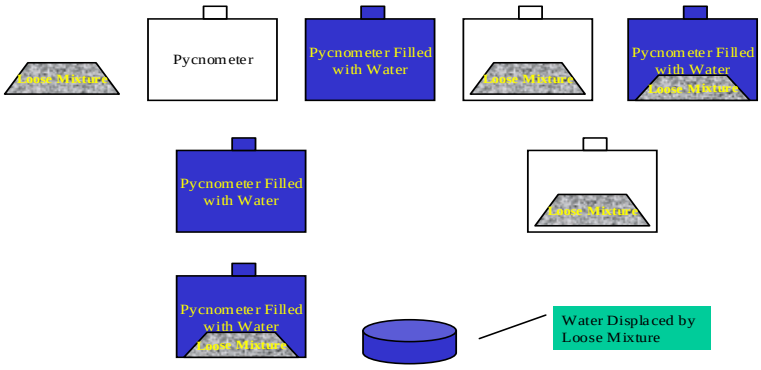
Maximum Specific Gravity of Compacted Mixture

AASHTO T- 209 for chosen Asphalt Content



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Bulk Gravity of Compacted Mixture

MASS in Grams

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

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Effective Specific Gravity of the Aggregates

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

Gb = Gravity of the Asphalt Cement

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

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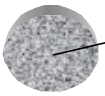
Va or VTM
% Air Voids or Voids in Compacted Mix



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

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

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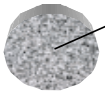
VMA
Voids in Mineral Aggregate



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

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

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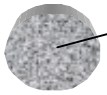
VFA
Voids Filled with Asphalt



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

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

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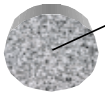
Effective Asphalt Content of a Paving Mixture



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

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

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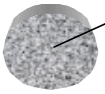
Asphalt Absorption



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

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

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MATERIALS & TESTS DIVISION

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	SSD	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

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MATERIALS & TESTS DIVISION

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**

TDOT
MATERIALS & TESTS DIVISION

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
	2.416
	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.

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Effective Specific Gravity of the Aggregates

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

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

Gse = Effective Specific Gravity of the Aggregates

Pmm = Percent by Mass of Total Loose Mixture (100.0)

Pb = Asphalt Content % by Total Mass of Mixture (4.0)

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

Gb = Gravity of the Asphalt Cement (1.032)

TDOT MATERIALS & TESTS DIVISION

Effective Specific Gravity of the Aggregates

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

$$Gse = \frac{100 - 4.0}{\frac{100}{2.532} - \frac{4.0}{1.032}} = \frac{96.0}{39.494 - 3.876} = \frac{96.0}{35.618} = 2.696$$

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.

TDOT MATERIALS & TESTS DIVISION

Va or VTM
% Air Voids or Voids in Compacted Mix

@ 4.0 % Asphalt Content

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

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)

TDOT
MATERIALS & TESTS DIVISION

Va or VTM
% Air Voids or Voids in Compacted Mix

@ 4.0 % Asphalt Content

$$Va = 100 \times \frac{2.532 - 2.421}{2.532}$$

$$= 100 \times \frac{0.111}{2.532}$$

$$= 100 \times 0.0438$$

$$= 4.4\ \%$$

Sample No.	% AC	% Agg.	Mass (grams) In Air	SSD	In Water	Volume (ml)	Bulk SG	Rice SG or TMD	VTM (%)
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		

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VMA
Voids in Mineral Aggregate

@ 4.0 % Asphalt Content

$$* \text{ VMA eff} = 100 - \frac{Gmb \times Ps}{Gse}$$

Vma eff = Voids in Mineral Aggregates using Effective Specific Gravity of the Aggregates

Gmb = Bulk Specific 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 eff = TDOT Definition**

TDOT
MATERIALS & TESTS DIVISION

VMA
Voids in Mineral Aggregate

@ 4.0 % Asphalt Content

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

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

$$= 100 - 86.2$$

$$= 13.8$$

Sample No.	% AC	% Agg.	Mass (grams) In Air	SSD	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			

TDOT
MATERIALS & TESTS DIVISION

VFA
Voids Filled with Asphalt

@ 4.0 % Asphalt Content

$$* \text{ VFA eff} = 100 \times \frac{\text{VMA eff} - \text{Va}}{\text{VMA eff}}$$

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**

TDOT
MATERIALS & TESTS DIVISION

VFA
Voids Filled with Asphalt

@ 4.0 % Asphalt Content

$$\text{VFA eff} = 100 \times \frac{13.8 - 4.4}{13.8}$$

$$= 100 \times \frac{9.4}{13.8}$$

$$= 100 \times 0.680$$

$$= 68.0$$

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				

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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

TDOT MATERIALS & TESTS DIVISION

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

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

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)

TDOT MATERIALS & TESTS DIVISION

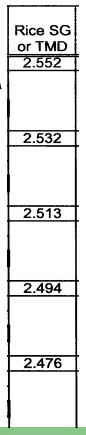
How to Calculate Gmm (Maximum Theoretical Specific Gravity of Paving Mixture) at all other Asphalt Contents

@ 3.5 % Asphalt Content

$$Gmm = \frac{Pmm}{\frac{Ps}{Gse} + \frac{Pb}{Gb}} = \frac{100}{\frac{96.5}{2.696} + \frac{3.5}{1.032}}$$

$$= \frac{100}{35.794 + 3.391}$$

$$= \frac{100}{39.186} = 2.552$$



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Preparing Graphs and Selecting Optimum

Bringing all our volumetric data together and putting it to use.

Preparing Graphs

- Now that we have build all the necessary pills at varying AC contents an tested them. We can utilize these numbers (VTM, VMA, etc) to select numbers for our design.

Preparing Graphs

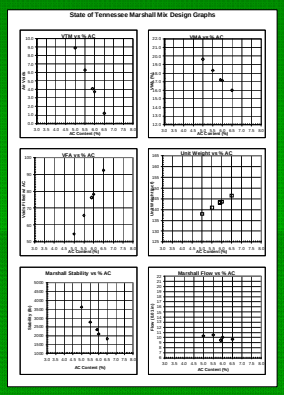
Turn this...

State of Tennessee Marshall Mix Design Sheet

Type of Mix	411-D PG 64-22	Contract No.	CNF191	Contractor	Concrete Structures
County	Hickman	Date	3/31/2008	Effective Gravity of Aggregate	2.614
Project Ref. No.	BR-STP-48(21)	Region	3	SG of Asphalt	1.032
HMA Producer	FUBANK ASPHALT, DICKSON PLANT #1			Number of Blows w/ Marshall Hammer	75

Sample No.	% AC	% Agg.	Mass (grams) In Air	Mass (grams) SSD	Mass (grams) In Water	Volume (ml)	Bulk SG	Rice SG @ TMD	VTM (%)	VMA (%)	VFA (%)	Unit Weight (pcf)	Stability (lb)	Flow (0.01 in)
1-1	5.0	95.0	1160.7	1161.7	638.7	523.0	2.221	2.428	8.9	19.6	54.7	138.6	3075	9.8
1-2			1156.6	1157.8	636.8	522.1	2.215						3600	10.3
1-3			1164.4	1165.8	638.7	526.9	2.210						3700	11.0
						Avg	2.212					Avg	3625	10.8
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	647.8	514.3	2.257						2400	9.5
2-3			1160.8	1161.7	648.6	513.1	2.262						3125	10.0
						Avg	2.259					Avg	2775	10.8
3-1	5.9	94.1	1160.8	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	6.8	94.0	1161.4	1162.3	659.2	503.1	2.308	2.394	3.7	17.1	78.2	143.8	2125	10.8
4-2			1159.6	1159.8	657.0	502.5	2.306						1950	10.9
4-3			1159.3	1159.9	655.5	504.4	2.298						2250	10.3
						Avg	2.304					Avg	2108	10.7
5-1	8.5	93.5	1155.3	1155.8	663.0	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	1160.8	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

Into this...

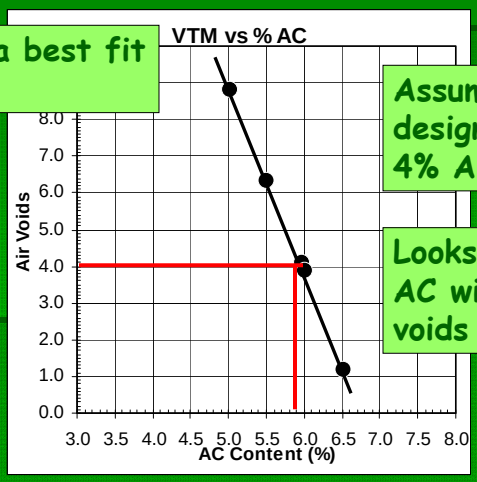


Preparing Graphs

- Our most important graph is the plot of AC content vs. Air Voids, which we will use to select our optimum AC%.

Preparing Graphs

Drawing a best fit line...



Assume we're designing for 4% Air Voids...

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

Preparing Graphs

- What about all those other numbers we calculated??

Preparing Graphs

- We'll plot the rest of our data (VMA, VFA, Unit Weight, Stability, and Flow) to observe our mix's behavior and make sure the mix will meet specs for VMA, Stability, and flow.

Voids in Mineral Aggregate (VMA)

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

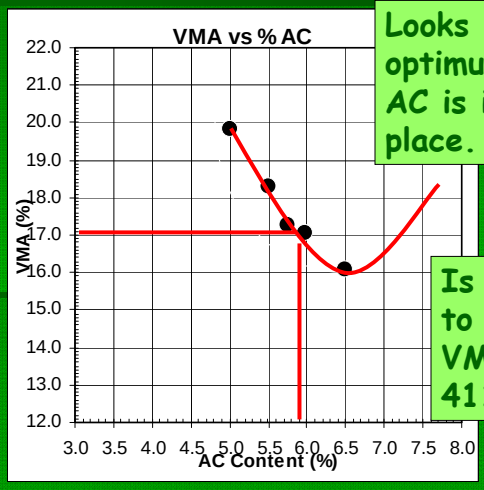
  411-D?

  307-BM2?

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.

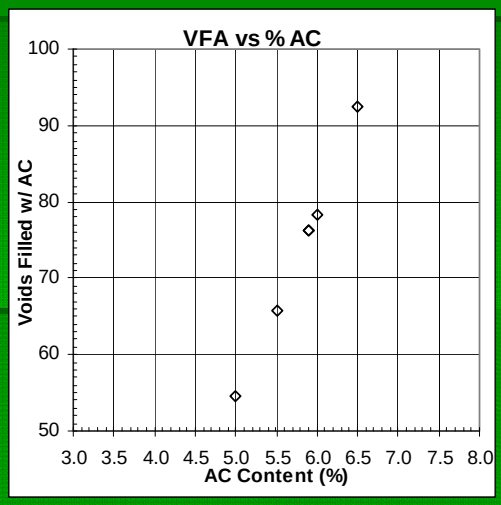
Voids in Mineral Aggregate (VMA)



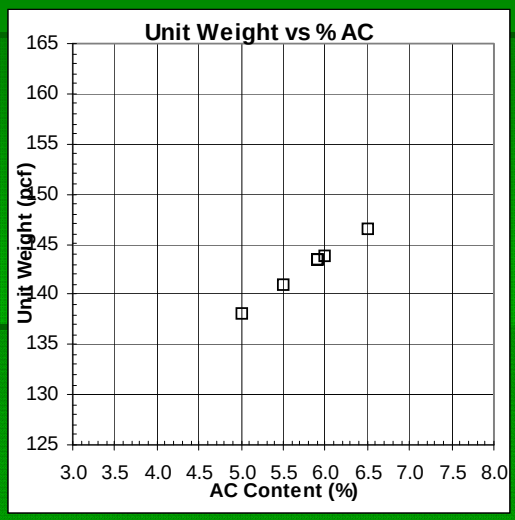
Looks like our optimum of 5.9% AC is in a good place.

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

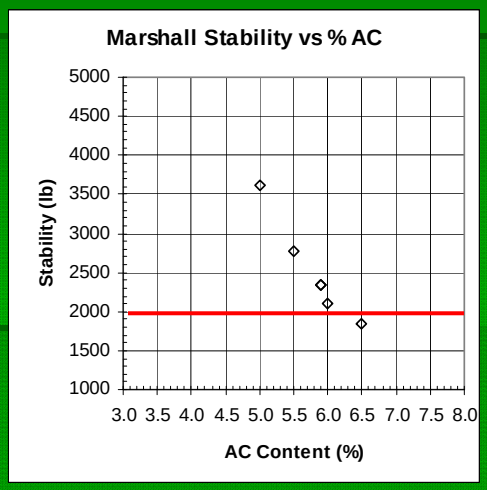
Voids Filled with Aggregate (VFA)



Unit Weight



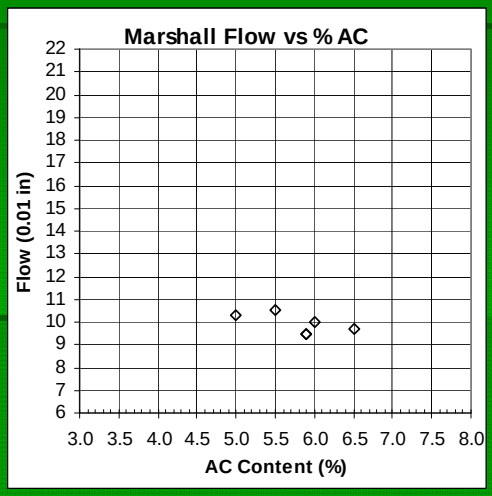
Marshall Stability



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

Is there any AC content that wouldn't meet spec?

Marshall Flow



How about these numbers?

Critical Mix Criteria

- Now that we've selected an optimum and checked our data graphically, we need to verify the "sensitivity" of our mix.

Critical Mix Criteria

TDOT Specs 407.03, (C), n.

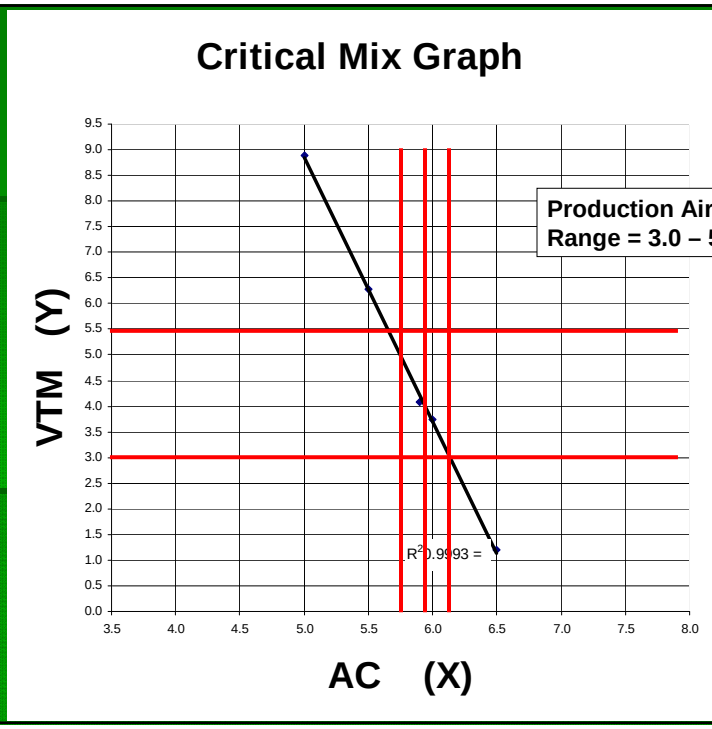
"In order to identify critical mixes and make appropriate adjustments, the mix design shall have the required design properties for the bitumen content range of Optimum Asphalt Cement ±0.25%

Critical Mix Criteria

What the heck does that mean???

Critical Mix Criteria

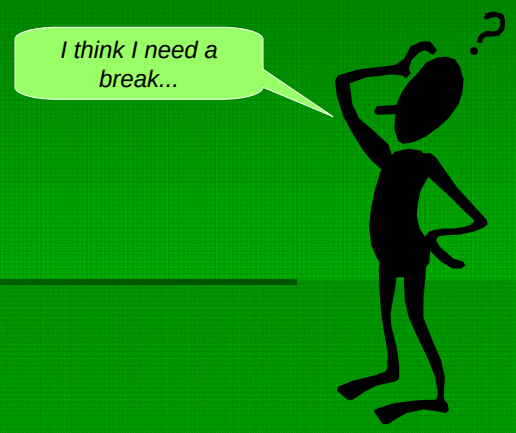
- We don't want a AC content versus Air Voids graph that is too "steep". Otherwise, a slight change in asphalt content could mean a big change in air voids.



Critical Mix Criteria

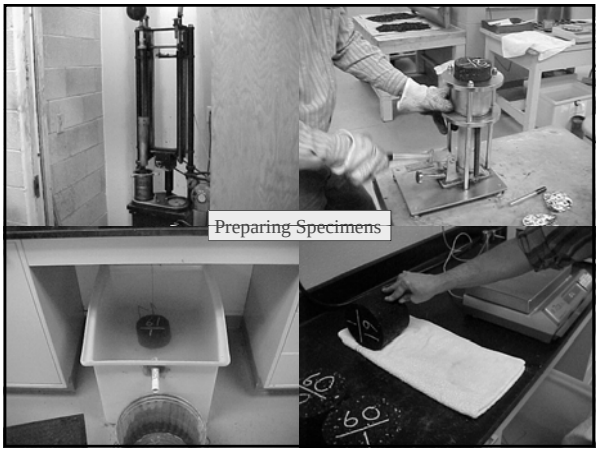
- Are we getting anything that plots outside of our allowable void content for production when we add or subtract 0.25% AC?
- If we were, what could we do to our design to correct it?

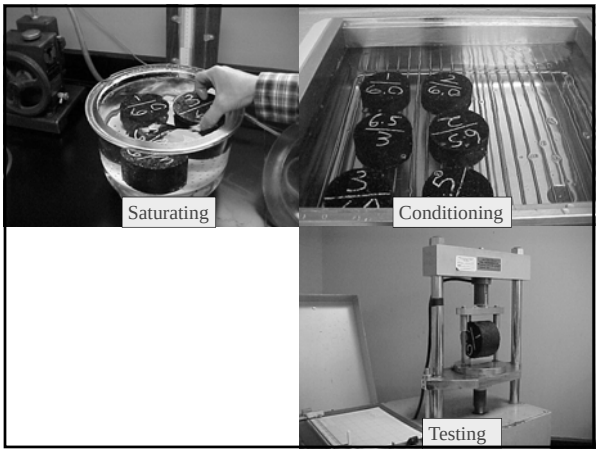
Questions?



ASTM D-4867

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





ASTM D-4867

TSR Test

•Some aggregate / asphalt combinations can be *Moisture Susceptible*.

➔ This is where water breaks the bond between asphalt cement and aggregate faces.

•This reaction is commonly known as *STRIPPING*, which has been known to cause premature rutting in mixtures.

•TDOT specs defend against moisture susceptible mixes with a minimum *TENSILE STRENGTH RATIO (TSR)* specification of 80%.

ASTM D-4867

TSR Test

Step 1:

Build 6 specimens at a void range between 6 and 8 percent?

ASTM D-4867

TSR Test

QUESTION...

If 75 blows gives me specimens with 4% voids...

How many blows give me 7%?

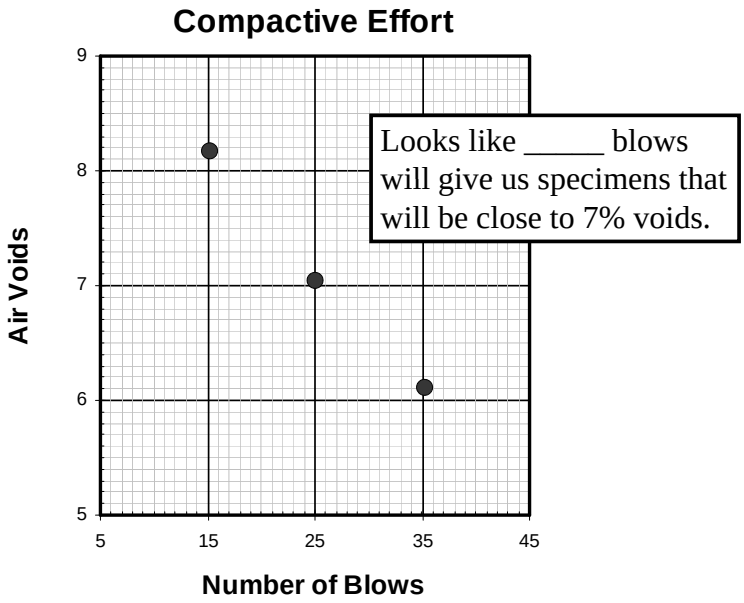
ASTM D-4867

TSR Test

We want higher voids (6-8%) for our TSR test than with Marshall pills (4%), so we first need to make some trial specimens to help estimate how many blows will get us with the 6 to 8 % void range.

of Blows

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					



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:

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

Example:

Initial Weight = 1200 grams

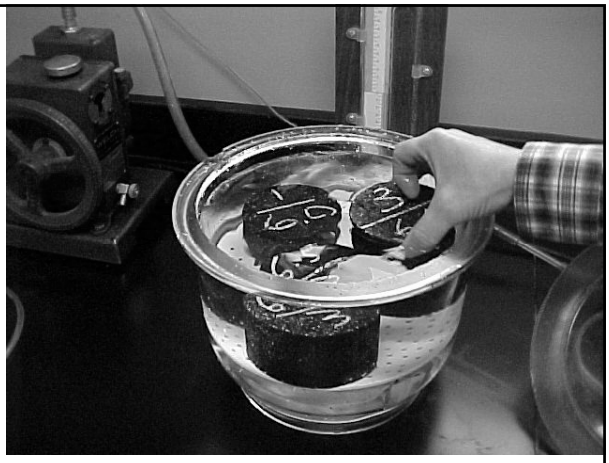
Measured Height = 2.60 inches

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

$$= \underline{\qquad\qquad}$$

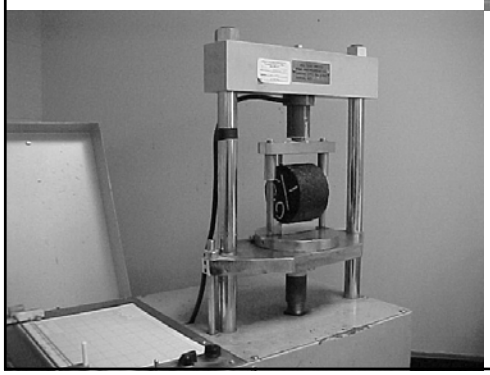
We're now ready to saturate the subset in a container of water by using a vacuum to "pull" water into the specimens for just a few seconds.

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's greater than 80 %?

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.

ASTM D4867
Tensile Strength Ratio (TSR)

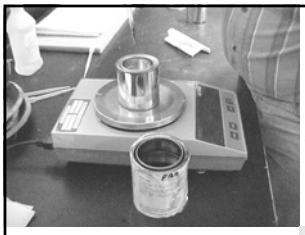
Fill this out along with the instructor

Sample I.D.		1	2	3	4	5	6
Diameter (D)		4.0	4.0	4.0	4.0	4.0	4.0
Thickness (T)		2.55	2.56	2.54	2.55	2.55	2.56
Dry mass in air (A)		1145.8	1148.0	1145.9	1143.3	1143.0	1144.3
SSD mass (B)		1148.3	1152.1	1149.1	1150.3	1146.1	1149.2
Mass in water (C)		635.7	637.9	634.4	636.4	632.6	634.6
Volume (E)	B-C						
Gmb (F)	A/E						
Gmm (G)		2.401	2.401	2.401	2.401	2.401	2.401
% Air Void (H)	(100(G-F)/G)						
Vol Air Voids (I)	(HE/100)						
Dry Load (P)							
SSD Mass (B')							
Vol. Abs. Water (J')	(B'-A)						
% Saturation	(100J'/I)						
Wet Load (P")							
Dry Strength (S_{td})	(2P/TDπ)						
Wet Strength (S_{tm})	(2P"/TDπ)						
TSR			Average both S_{td} and S_{tm} before calculating TSR				

Ten Minute Boil Test Antistrip Additive

(Field Test / Laboratory Test)

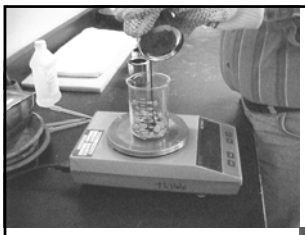
Referenced in TDOT Specifications section 407.03 (E)



* Prepare approximately 500g of +4 material
* Weigh out approx. 100g of agg. into 3 (three) 400ml beakers
* Heat agg. and approx ¾ qt A/C to 300 ± 10º F for 30 min.
* Prepare 2 (two) smaller cans with 0.3% and 0.5% of selected additive

* Add 100g of hot A/C to each small can
* A third can will contain A/C only

* Stir the A/C & Anti-strip thoroughly

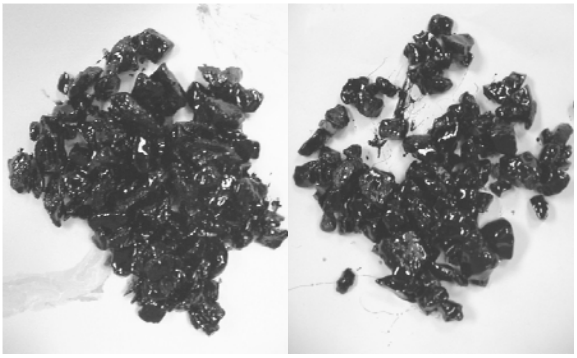


* Add 100g of hot aggregate to each beaker
* Thoroughly blend 5g of A/C to 100g of aggregate in beaker

* Pour out onto separate pieces of waxed paper identifying additive amounts
* Allow mixture to cool to room temperature

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

* Visually inspect material for evidence of striping
* Choose lowest rate with no evidence of striping



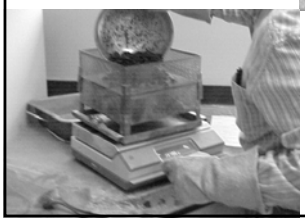
Which has more stripping?

AASHTO T-308
Determining the Asphalt Binder Content of HMA by the Ignition

AASHTO T-308
Determining the Asphalt Binder Content of HMA by the Ignition Method

- Furnace must be calibrated to <u>each different mix</u>.
- Use of furnace MUST be backed up weekly with a solvent extraction.
- Test is to be run at 538° C.
- Watch for broken aggregate.
- Do not use the furnace to cook Pilsbury canned biscuits.

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



Split the sample evenly between the two sample baskets…

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

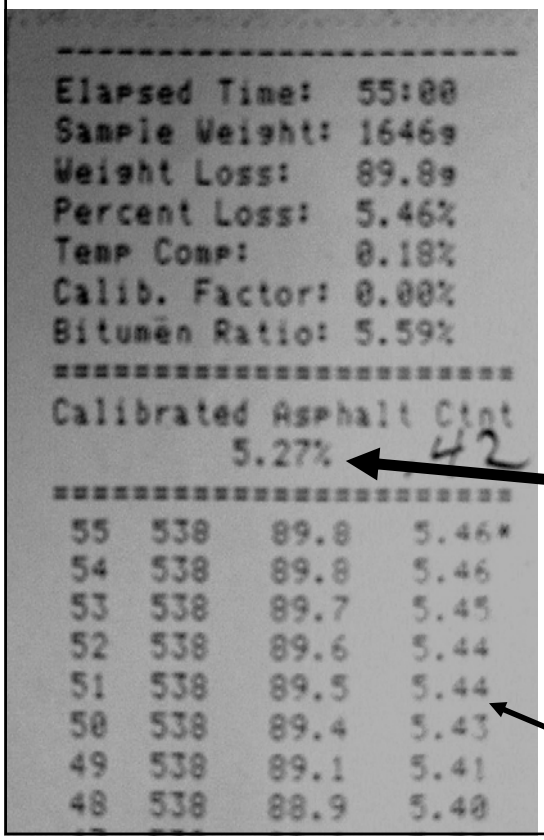
Stack baskets and lock cover into place.

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.

AASHTO T-308

Calculations



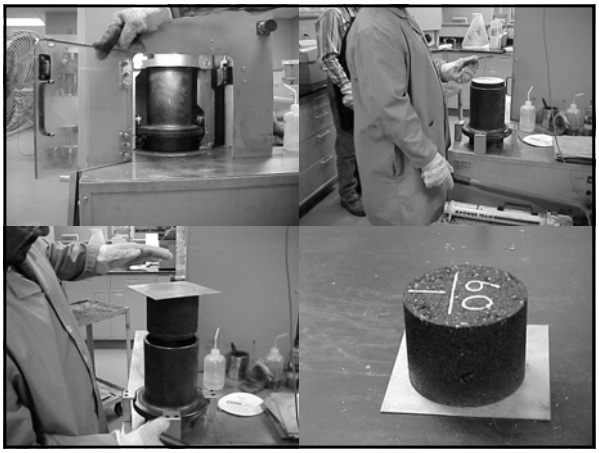
```
-----------------------
Elapsed Time:   55:00
Sample Weight:  1646g
Weight Loss:    89.8g
Percent Loss:   5.46%
Temp Comp:      0.18%
Calib. Factor:  0.00%
Bitumen Ratio:  5.59%
=======================
Calibrated Asphalt Ctnt
        5.27%
=======================
 55  538   89.8   5.46*
 54  538   89.8   5.46
 53  538   89.7   5.45
 52  538   89.6   5.44
 51  538   89.5   5.44
 50  538   89.4   5.43
 49  538   89.1   5.41
 48  538   88.9   5.40
```

(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. (from JMF)	5.4
A. C. Content from N.C.A.T.tape	5.27
A.C. Content Deviation	**-0.13**

Test Print-out

AASHTO T-312

Standard Method of Preparing and Determining the Density of Hot-Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor



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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 (Soft) Screenings**

T-27 RESULTS

U.S. STANDARDS SIEVES	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			
NO. 8	450.9			
NO. 16				
NO. 30	1040.2			
NO. 50	1188.2			
NO. 100	1231.2			
NO. 200	1290.0			
Minus #200				
TOTAL			UNACCEPTABLE	99.7-100.3

Class Room Example
Monday

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

Always click "Finish Editing Gradations" button after Gradations have been edited.

	1	2	3	4	5	6
Material	D Rock(Limestone)	#10 (Soft)	Natural Sand		0 RAP	
Size	Medium Coarse Aggr	Medium Coarse Agg	Natural Sand			Minus 1/2 inch Rap
Producer and Location (As shown in TDOT's Producer Listing)						
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
#4		27.5		97.0		74.0
#8		6.0		82.0		52.0
#16						
#30		3.0		67.0		30.0
#50		2.0		14.0		24.0
#100		1.5		3.0		17.0
#200		1.0		1.0		12.0
RAP AC Content						5.7

Class Room Example

Monday

STATE OF TENNESSEE ASPHALT JOB MIX FORMULA

1/31/2007 V6.0

L-13. L-20

Project Ref. No.	STP-99-3(22)	**Date**	03/12/2007
Project No.	44444-2222-11	**Region**	3
Contract No.	Z-000	**County**	Bedford Co.
Contractor	Watts Paving INC.	**Date of Letting**	09/25/06
State Route No.	SR-1	**Roadway Surface**	Yes
Hot-mix Producer	ROGERS GROUP, INC., 2880 WAYNESBORO HWY.		

Type ACS-HM **Mix** 411-D w/ RAP PG 64-22 **Item**

Serial No.:	Design No.:

Material	Size or Grade	Producer and Location	Percent Used
D Rock(Limestone)	Medium Coarse Aggregate		50.000
#10 (Soft)	Medium Coarse Aggregate		10.000
Natural Sand	Natural Sand		25.000
RAP	Minus 1/2 inch Rap		15.907
Asphalt Cement	PG 64-22	ERGON ASPHALT & EMULSIONS, MEMPHIS, TN	

Class Room Example
Monday

Percent AC in RAP:	5.7	**Optimum AC Content:**		**Total**	100.907
Anti-Strip Additive:		Armaz Adhere 7700/Plant		**Dosage:**	0.5%
AC Contribution:	**Virgin AC**		**RAP AC**		**Percent Virgin AC:**
Asphalt Sp. Gravity:		1.032		**Dust to Asphalt Ratio:**	

% Fracture Face on CA:	**% Glassy Particles on CA:**
Theo.Gravity of RAP:	**Eff. Gravity of Agg:**

Theo. Gravity of Mix:	**T.S.R.:**	**Lbs/Ft^3:**
L.O.I.:		**Ignition Oven Corr. Factor:**
ADT	**Log Miles** **Beginning:**	**Ending:**

Lab Temperature		**Plant Temperature**	
Mixing Temperature (± 5 °F):	**300**	**Mixing Temp Range(°F):**	**290ºF ≤ T ≤ 320ºF**
Lab Compaction Temp (± 5 °F):	**280**	**Delivery Temperature(°F):**	**290ºF ≤ T ≤ 320ºF**

	Percents Used								
Sieve Size	**D Rock(Limestone)** 50.0	**#10 (Soft)** 10.0	**Natural Sand** 25.0				**RAP** 15.0	**% Req. 100**	**Design Range**
2"									
1.5"									
1.25"									
1"									
3/4"									
5/8"									
1/2"									
3/8"									
No.4									
No.8									
No.16									
No.30									
No.50									
No.100									
No.200									

Requested: _____ Contractor Personnel and Lab Tech Cert No.

Approved: _____ Regional Materials and Tests Supervisor

Date last lab inspection 3

Approved: _____ Headquarters Materials and Tests

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

Mix Type 411-D w/ RAP PG 64-22

Wt. Total Aggregate Blend 5000 grams

Blend Name

Contract No. Z-000

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

Class Room Example

Monday

	Sized Fractions	% Passing	Ind. % Retained	Ind wt. Retained	Accum. wt.
1)	1.5"/1.25"				
	1"				
	3/4"				
	1/2"				
	3/8"				
	#4				
	#8				
	-#8				
2)	1.5"/1.25"				
	1"				
	3/4"				
	1/2"				
	3/8"				
	#4				
	#8				
	-#8				
3)	1/2"				
	3/8"				
	#4				
	#8				
	-#8				
4)	1/2"				
	3/8"				
	#4				
	#8				
	-#8				
5)	1/2"				
	3/8"				
	#4				
	#8				
	-#8				

	3/8"				
	#4				
6)	#8				
	#30				
	-#30				

	1/2"				
	3/8"				
7)	#4				
	#8				
	-#8				

Asphalt Liquid Calculation

Desired AC Content	Binder Weight
4.00	
4.50	
5.00	
5.50	
6.00	
6.50	

Specific Gravity and Absorption of Aggregates

AASHTO T-84 AND T-85

Blended Aggregates

From the Job Mix Formula: % Passing #4 Sieve _____

% Retained on #4 Sieve _____

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

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

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

Class Room Example

Tuesday

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

Bulk Sp. Gr. $= \frac{A}{B - C} =$ _____

Apparent Sp. Gr. $= \frac{A}{A - C} =$ _____

% Absorption $= \frac{B - A}{A} \times 100\% =$

$=$ _____ %

Combined Specific Gravity $\dfrac{100}{\dfrac{\%\ F.\ A.}{Sp.\ Gr.\ F.A.} + \dfrac{\%\ C.\ A.}{Sp.\ Gr.\ C.A.}} =$

Combined Bulk Specific Gravity (Gsb) _____

Combined Apparent Specific Gravity (Gsa) _____

Combined Blend Absorption _____

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

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

Class Room Example
Tuesday

Combined Masses from above:

Mass of Test Samples _____ g

Mass of Losses _____ g

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

% L. O. I. _____

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.

Class Room Example
Tuesday

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

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

% Fractured = _____ %

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

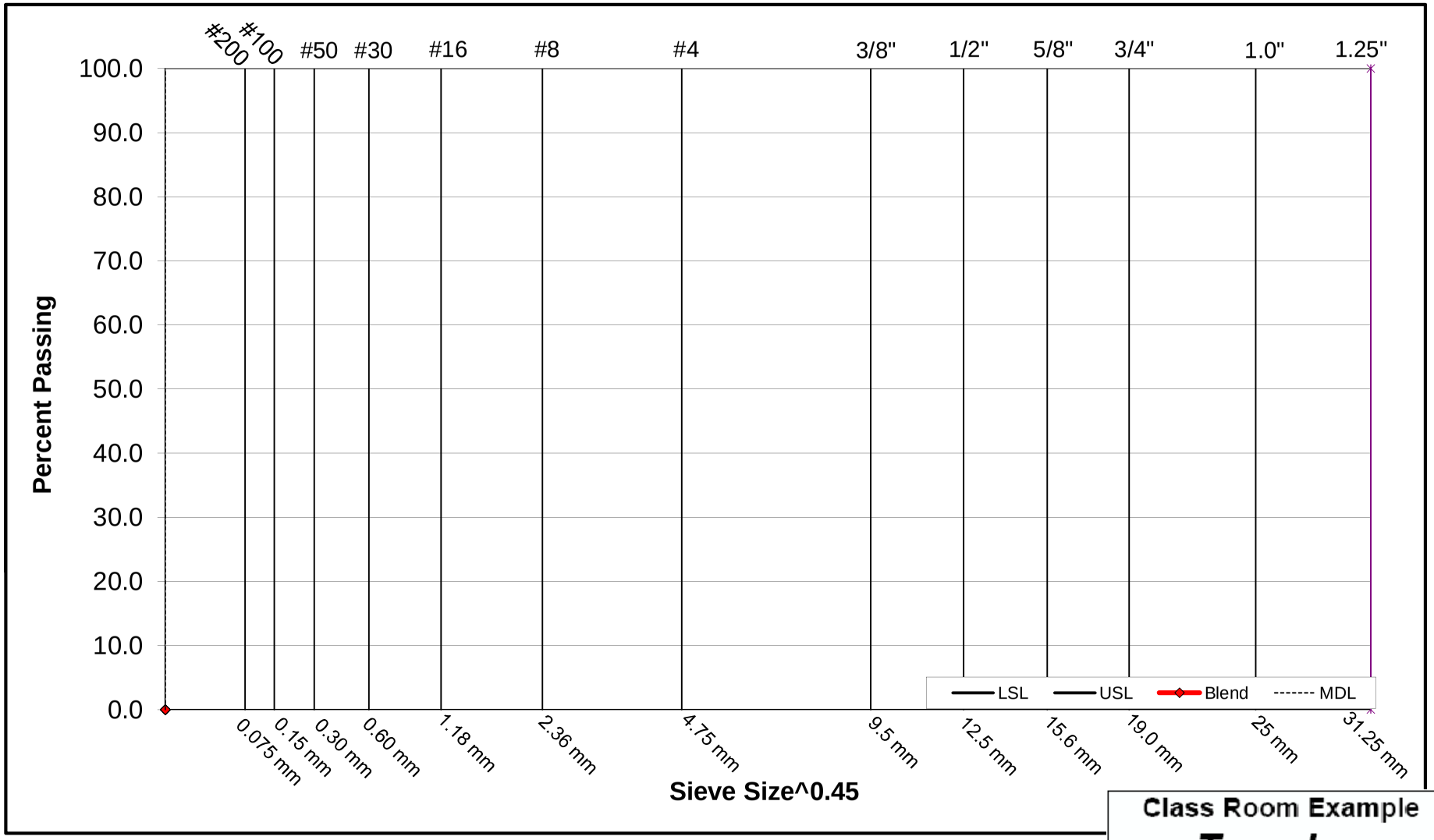
Class Room Example

Tuesday

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

Mass of Glassy Particles	36.3	g
Total Mass of Sample Used	427.9	g

% Glassy Particles = _____ %



Class Room Example

Tuesday

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

Project Ref. No.	STP-99-3(22)	**Date**	03/12/07
Project No.	44444-2222-11	**Region**	3
Contract No.	Z-000	**County**	Bedford Co.
Contractor	Watts Paving INC.	**Date of Letting**	09/25/2006
State Route No.	SR-1		
Mix Type	411-D w/ RAP PG 64-22		
HMA Producer	ROGERS GROUP, INC., 2880 WAYNESBORO HWY.		

CALCULATION OF MAXIMUM SPECIFIC GRAVITY:

		(1)	(2)	(3)
FLASK	% AC	5.9		
	WT. DRY SAMPLE + FLASK (grams)	3927.7		
	WT. FLASK (grams)	2177.0		
	WT. DRY SAMPLE (A) (grams)			
	WT. FLASK FILLED WITH WATER (D) (grams)	7399.0		
	WT. FLASK FILLED WITH WATER & DRY SAMPLE (E) (grams)	8424.3		
	MAXIMUM SPECIFIC GRAVITY MIX (G_{mm}) = $\frac{A}{A + D - E} \Rightarrow$			

CALCULATION OF THE EFFECTIVE GRAVITY OF THE AGGREGATES:

% AGGREGATES			
SPECIFIC GRAVITY OF ASPHALT CEMENT	1.032	1.032	1.032

Effective Specific Gravity of Aggregates (G_{se})

$$G_{se} = \frac{\% \text{ AGG}}{\frac{100}{G_{mm}} - \frac{\% \text{ AC}}{G_b}}$$

Avg. Effective Gravity _____

Class Room Example

Wednesday

RICE VALUES AT OTHER ASPHALT CONTENTS

Percent Asphalt	Theoretical Maximum Density
7.0	
6.5	
6.0	
5.5	
5.0	

State of Tennessee Marshall Mix Design Sheet

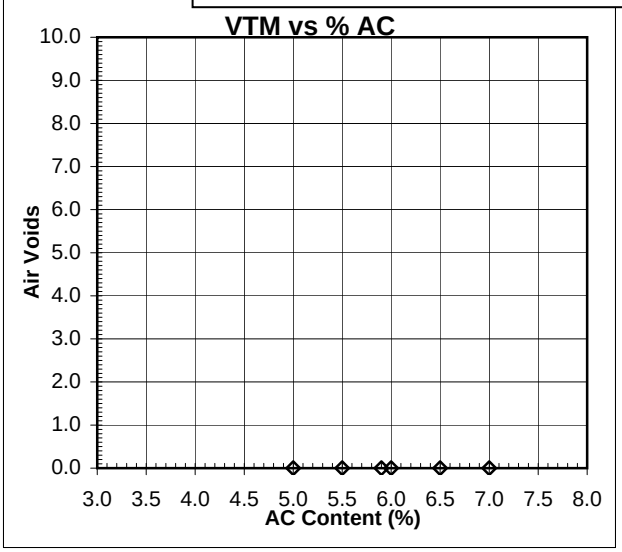
Class Room Example
Wednesday

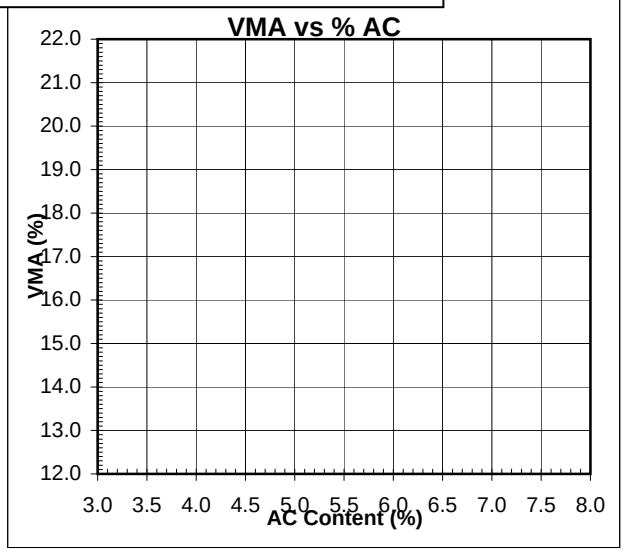
Type of Mix	411-D w/ RAP PG 64-22	Contractor	Watts Paving INC.
County	Bedford Co.	Effective Gravity of Aggregate	
Project Ref. No.	STP-99-3(22)	SG of Asphalt	1.032
HMA Producer	ROGERS GROUP, INC.	Number of Blows w/ Marshall Hammer	75

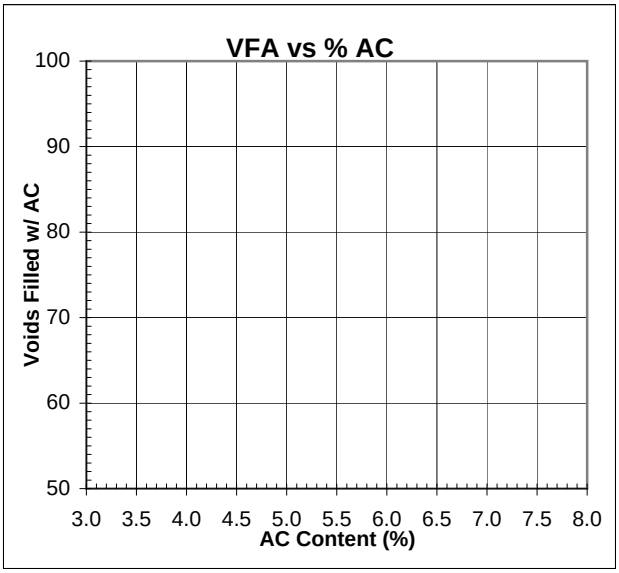
Sample No.	% AC	% Agg.	Mass (grams) In Air	SSD	In Water	Volume (ml)	Bulk SG	Rice SG or TMD	VTM (%)	VMA (%)	VFA (%)	Unit Weight (pcf)	Stability (lb)	Flow (0.01")
1-1	5.0		1177.2	1181.4	666.2								2750	10.0
1-2			1179.6	1183.9	668.7								2800	9.0
1-3			1175.8	1178.9	665.0								2850	9.0
						Avg						Avg		
2-1	5.5		1181.4	1183.9	668.0								2650	11.0
2-2			1178.2	1181.5	669.2								2700	10.0
2-3			1177.4	1179.3	671.1								2725	10.0
						Avg						Avg		
3-1	6.0		1182.1	1183.0	672.3								2625	12.0
3-2			1180.4	1181.2	674.1								2650	12.0
3-3			1181.6	1182.6	672.0								2600	12.0
						Avg						Avg		
4-1	6.5		1179.4	1180.3	673.4								2475	13.0
4-2			1181.7	1182.5	675.5								2450	12.0
4-3			1180.9	1181.6	672.6								2500	12.5
						Avg						Avg		
5-1	7.0		1177.2	1178.0	675.2								2200	13.5
5-2			1179.6	1180.1	677.9								2150	13.0
5-3			1181.0	1181.5	674.0								2075	13.5
						Avg						Avg		
Opt-1	5.9		1181.9	1182.4	671.4								2550	12.0
Opt-2			1182.4	1183.5	672.6								2600	12.0
Opt-3			1180.0	1181.2	672.7								2625	12.0
						Avg						Avg		

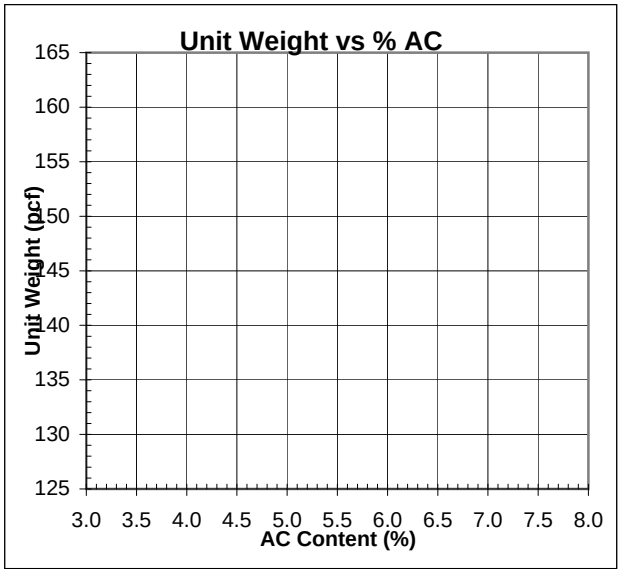
State of Tennessee Marshall Mix Design Graphs

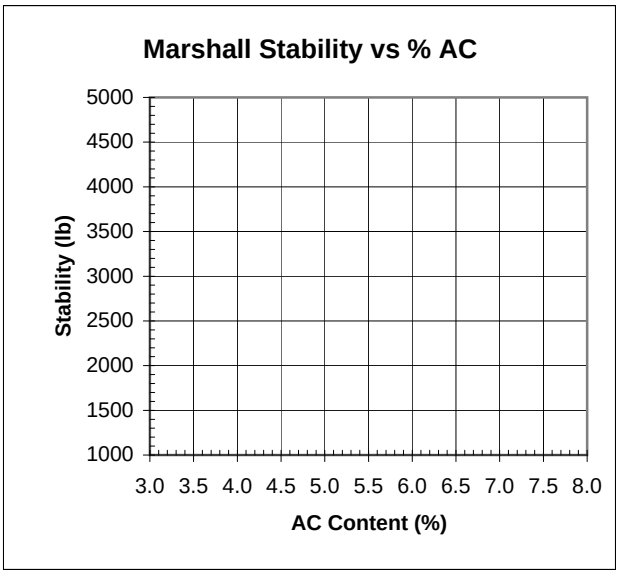
Class Room Example *Wednesday*

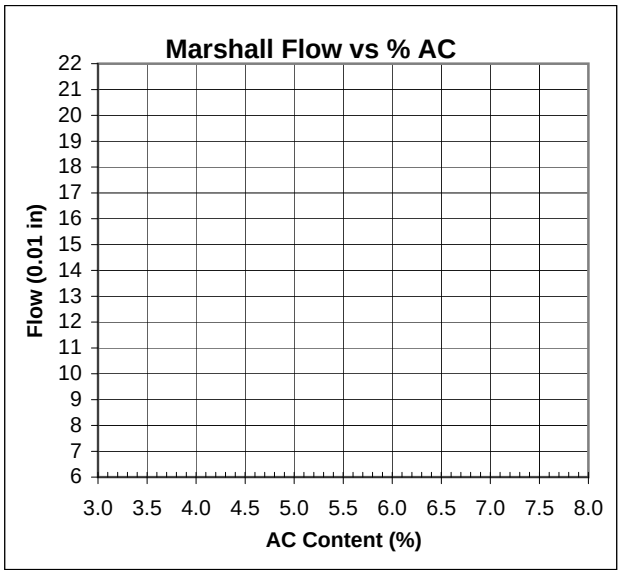




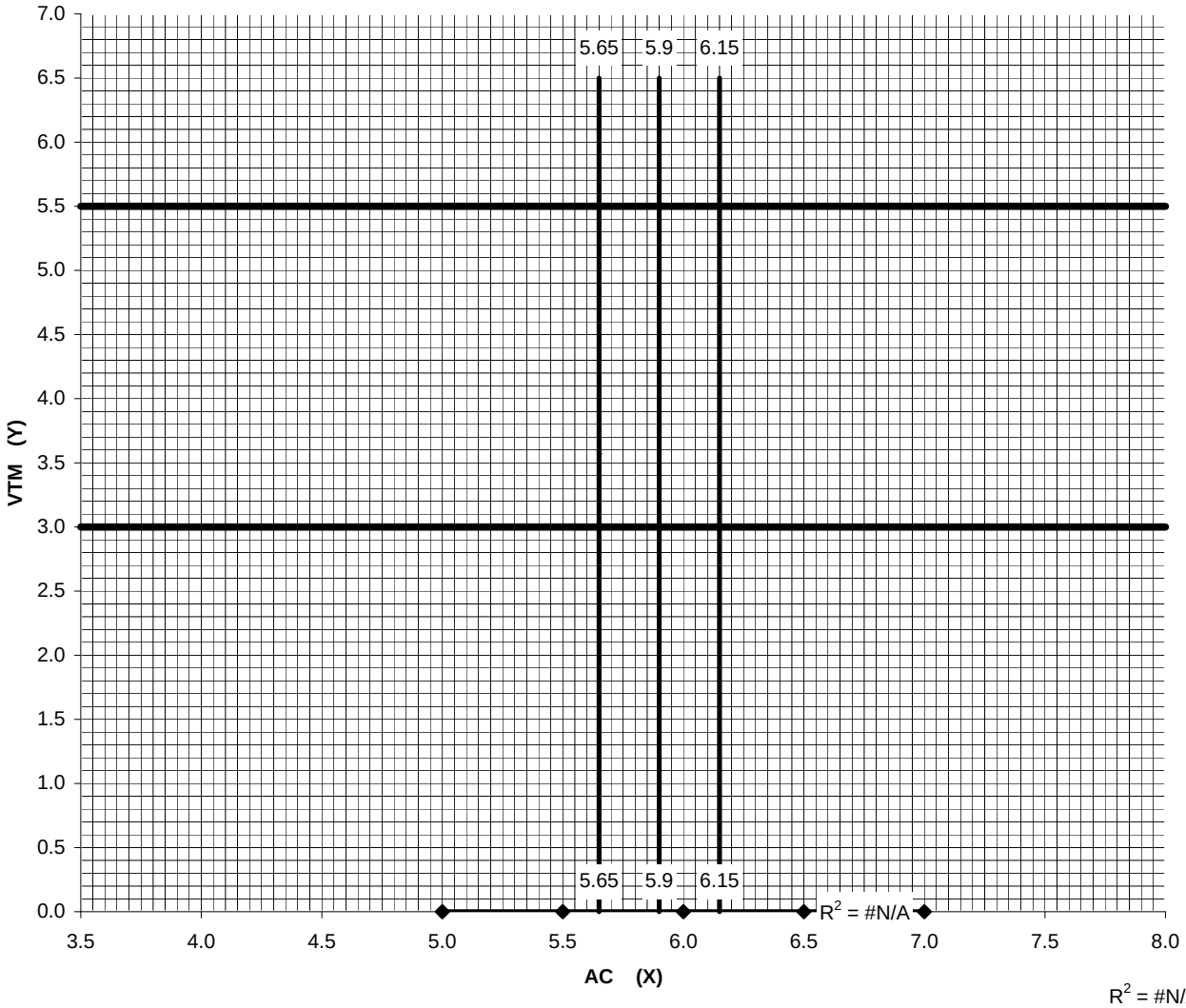








Critical Mix Graph



R^2 = #N/A

Determining Blow Count For TSR

ASTM D 4867

Lab Log #: _____

Trial Blow Effort		15	25	40
Diameter	*D*	4.0	4.0	4.0
Thickness	*T*	N/A		
Dry Mass in Air	*A*	1199.5	1199.2	1192.5
SSD Mass	*B*	1205.0	1209.2	1193.5
Mass in Water	*C*	663.2	672.0	670.2
Volume (*B-C*)	*E*			
Gmb (*A/E*)	*F*			
Gmm	*G*	2.413	2.413	2.413
% Air Voids (100(*G-F*)/*G*)	*H*			
Vol. Air Voids (*HE*/100)	*I*	N/A		

Effort

Comments:

Class Room Example

Thursday

Height Adjustment Calculation

Desired Ht.	2.500
Measured Wt.	1200.0
Measured Ht.	2.600
Mtrl. Required	1153.8

Marshall Test Specimen

Class Room Example
Thursday

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:

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

Example:

Initial Weight = 1200 grams

Measured Height = 2.60 inches

Adjusted weight =

= _____

ASTM D 4867
MOISTURE DAMAGE LABORATORY DATA SHEET

Contract No. Z-000
Mix Type 411-D w/ RAP PG 64-22
Additive: Armaz Adhere 7700/Pla Dosage: 0.50%
Compaction Method: Marshall Hammer Effort: 28 Blows
Aggregate Effective Gravity: Opt. AC content (%): 5.9
Date Tested: By:

Sample I.D.		1	2	3	4	5	6
Diameter (D)		4.00	4.00	4.00	4.00	4.00	4.00
Thickness (t)		2.50	2.50	2.50	2.50	2.50	2.50
Dry mass in air (A)		1179.4	1176.2	1177.2	1177.4	1177.4	1180.2
SSD mass (B)		1185.3	1184.5	1185.9	1185.2	1182.8	1186.3
Mass in water (C)		659.5	660.1	661.4	661.2	658.0	660.3
Volume(E)	B-C						
Bulk Sp. Gr. (F)	A/E						
Max. Sp. Gravity (G)							
% Air Void	(100(G-F)/G)						
Condition Specimen: (x)		☑	☑	☑	☐	☐	☐
Saturated	0.25	min. @		in. Hg			
SSD Mass		1203.5	1201.8	1202.4			
Degree of Saturation 55<S<80							
Conditioned 24h in 140°F water.							
Thickness (t)							
Load (P)		1925	1850	1900	2010	2150	1975
Dry (STd)	see Note 1						
Wet (STm)	see Note 1						
Results							
TSR							
Visual Moisture Damage		1					
Visual Aggregate Breakage			1				

CONDITIONED = _____ UNCONDITIONED = _____

Note 1:

$$\text{TENSILE STRENGTH (psi)} = \frac{2P}{\pi t D}$$

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Designation: D75/D75M – 09

American Association State Highway and Transportation Officials Standard AASHTO No.: T2

Standard Practice for Sampling Aggregates[1]

This standard is issued under the fixed designation D75/D75M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice covers sampling of coarse and fine aggregates for the following purposes:

1.1.1 Preliminary investigation of the potential source of supply,

1.1.2 Control of the product at the source of supply,

1.1.3 Control of the operations at the site of use, and

1.1.4 Acceptance or rejection of the materials.

NOTE 1—Sampling plans and acceptance and control tests vary with the type of construction in which the material is used.

1.2 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

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

NOTE 2—The quality of the results produced by this standard are dependent on the competence of the personnel performing the procedure and the capability, calibration, and maintenance of the equipment used. Agencies that meet the criteria of Practice D3666 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3666 alone does not completely assure reliable results. Reliable results depend on many factors; following the suggestions of Practice D3666 or some similar acceptable guideline provides a means of evaluating and controlling some of those factors.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C125 Terminology Relating to Concrete and Concrete Aggregates

C702 Practice for Reducing Samples of Aggregate to Testing Size

D8 Terminology Relating to Materials for Roads and Pavements

D2234/D2234M Practice for Collection of a Gross Sample of Coal

D3665 Practice for Random Sampling of Construction Materials

D3666 Specification for Minimum Requirements for Agencies Testing and Inspecting Road and Paving Materials

E105 Practice for Probability Sampling Of Materials

E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

E141 Practice for Acceptance of Evidence Based on the Results of Probability Sampling

3. Terminology

3.1 *Definitions:*

3.1.1 *maximum size of aggregate, n—in specifications for, or descriptions of aggregate*—the smallest sieve opening through which the entire amount of aggregat is required to pass. **C125,D8**

3.1.2 *maximum aggregate size, (Superpave) n—in specifications for, or descriptions of aggregate*—one size larger than the nominal maximum aggregate size.

3.1.3 *nominal maximum aggregate size (of aggregate), n—in specifications for, or descriptions of aggregate*—the smallest sieve opening through which the entire amount of the aggregate is permitted to pass. **C125, D8**

3.1.4 *nominal maximum aggregate size (Superpave), n—in specifications for, or descriptions of aggregate*—one size larger than the first sieve that retains more than 10 % aggregate.

[1] This practice is under the jurisdiction of ASTM Committee D04 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.30 on Methods of Sampling.

Current edition approved June 1, 2009. Published June 2009. Originally approved in 1920. Last previous edition approved in 2003 as D75 – 03. DOI: 10.1520/D0075_D0075M-09.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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3.1.4.1 *Discussion*—These definitions in 3.1.2 and 3.1.4 apply to hot mix asphalt (HMA) mixtures designed using the Superpave system only, and differ from the definitions published in D8

3.1.4.2 *Discussion*—Specifications on aggregates usually stipulate a sieve opening through which all of the aggregate may, but not need to, pass so that a slated maximum portion of the aggregate may be retained on that sieve. A sieve opening so designed is the *nominal maximum size*.

4. Significance and Use

4.1 Sampling is equally as important as the testing, and the sampler shall use every precaution to obtain samples that will show the nature and condition of the materials which they represent.

4.2 Samples for preliminary investigation tests are obtained by the party responsible for development of the potential source (Note 3). Samples of materials for control of the production at the source or control of the work at the site of use are obtained by the manufacturer, contractor, or other parties responsible for accomplishing the work. Samples for tests to be used in acceptance or rejection decisions by the purchaser are obtained by the purchaser or his authorized representative.

NOTE 3—The preliminary investigation and sampling of potential aggregate sources and types occupies a very important place in determining the availability and suitability of the largest single constituent entering into the construction. It influences the type of construction from the standpoint of economics and governs the necessary material control to ensure durability of the resulting structure, from the aggregate standpoint. This investigation should be done only by a responsible trained and experienced person. For more comprehensive guidance, see the Appendix.

5. Securing Samples

5.1 *General*—Where practicable, samples to be tested for quality shall be obtained from the finished product. Samples from the finished product to be tested for abrasion loss shall not be subject to further crushing or manual reduction in particle size in preparation for the abrasion test unless the size of the finished product is such that it requires further reduction for testing purposes.

5.2 *Inspection*—The material shall be inspected to determine discernible variations. The seller shall provide suitable equipment needed for proper inspection and sampling.

5.3 *Procedure*:

5.3.1 *Sampling from a Flowing Aggregate Stream (Bins or Belt Discharge)*—Select units to be sampled by a random method, such as Practice D3665, from the production. Obtain at least three approximately equal increments, selected at random from the unit being sampled, and combine to form a field sample whose mass equals or exceeds the minimum recommended in 5.4.2. Take each increment from the entire cross section of the material as it is being discharged. It is usually necessary to have a special device constructed for use at each particular plant. This device consists of a pan of sufficient size to intercept the entire cross section of the discharge stream and hold the required quantity of material without overflowing. A set of rails may be necessary to support the pan as it is passed under the discharge stream. Insofar as is possible, keep bins continuously full or nearly full to reduce segregation.

NOTE 4—Sampling the initial discharge or the final few tons from a bin or conveyor belt increases the chances of obtaining segregated material and should be avoided.

5.3.2 *Sampling from the Conveyor Belt*—Select units to be sampled by a random method, such as Practice D3665, from the production. Obtain at least three approximately equal increments, selected at random, from the unit being sampled and combine to form a field sample whose mass equals or exceeds the minimum recommended in 5.4.2. Stop the conveyor belt while the sample increments are being obtained. Insert two templates, the shape of which conforms to the shape of the belt in the aggregate stream on the belt, and space them such that the material contained between them will yield an increment of the required weight. Carefully scoop all material between the templates into a suitable container and collect the fines on the belt with a brush and dust pan and add to the container.

5.3.3 *Sampling from Stockpiles or Transportation Units*—Avoid sampling coarse aggregate or mixed coarse and fine aggregate from stockpiles or transportation units whenever possible, particularly when the sampling is done for the purpose of determining aggregate properties that may be dependent upon the grading of the sample. If circumstances make it necessary to obtain samples from a stockpile of coarse aggregate or a stockpile of combined coarse and fine aggregate, design a sampling plan for the specific case under consideration. This approach will allow the sampling agency to use a sampling plan that will give a confidence in results obtained therefrom that is agreed upon by all parties concerned to be acceptable for the particular situation. The sampling plan shall define the number of samples necessary to represent lots and sublots of specific sizes. General principles for sampling from stockpiles are applicable to sampling from trucks, rail cars, barges, or other transportation units. For general guidance in sampling from stockpiles, see the Appendix.

5.3.4 *Sampling from Roadway (Bases and Subbases)*—Sample units selected by a random method, such as Practice D3665, from the construction. Obtain at least three approximately equal increments, selected at random from the unit being sampled, and combine to form a field sample whose mass equals or exceeds the minimum recommended in 5.4.2. Take all increments from the roadway for the full depth of the material, taking care to exclude any underlying material. Clearly mark the specific areas from which each increment is to be removed: a metal template placed over the area is a definite aid in securing approximately equal increment weights.

5.4 *Number and Masses of Field Samples*:

5.4.1 The number of field samples (obtained by one of the methods described in 5.3) required depends on the criticality of, and variation in, the properties to be measured. Designate each unit from which a field sample is to be obtained prior to sampling. The number of field samples from the production should be sufficient to give the desired confidence in test results.

NOTE 5—Guidance for determining the number of samples required to obtain the desired level of confidence in test results may be found in Test Method D2234/D2234M, Practice E105, Practice E122, and Practice E141.

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5.4.2 The field sample masses cited are tentative. The masses must be predicated on the type and number of tests to which the material is to be subjected and sufficient material obtained to provide for the proper execution of these tests. Standard acceptance and control tests are covered by ASTM standards and specify the portion of the field sample required for each specific test. Generally speaking, the amounts specified in Table 1 will provide adequate material for routine grading and quality analysis. Extract test portions from the field sample according to Practice C702 or as required by other applicable test methods.

6. Shipping Samples

6.1 Transport aggregates in bags or other containers so constructed as to preclude loss or contamination of any part of the sample, or damage to the contents from mishandling during shipment.

6.2 Shipping containers for aggregate samples shall have suitable individual identification attached and enclosed so that field reporting, laboratory logging, and test reporting may be facilitated.

7. Keywords

7.1 aggregates; exploration of potential sources; aggregates; number and sizes needed to estimate character; aggregates; sampling

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TABLE 1 Size of Samples

Aggregate Size[A]	Field Sample Mass, min, kg[B] [lbs]	Field Sample Volume, min, L [Gal]
	Fine Aggregate	
2.36 mm [No. 8]	10 [22]	8 [2]
4.75 mm [No. 4]	10 [22]	8 [2]
	Coarse Aggregate	
9.5 mm [⅜ in.]	10 [22]	8 [2]
12.5 mm [½ in.]	15 [35]	12 [3]
19.0 mm [¾ in.]	25 [55]	20 [5]
25.0 mm [1 in.]	50 [110]	40 [10]
37.5 mm [1½ in.]	75 [165]	60 [15]
50 mm [2 in.]	100 [220]	80 [21]
63 mm [2½ in.]	125 [275]	100 [26]
75 mm [3 in.]	150 [330]	120 [32]
90 mm [3½ in.]	175 [385]	140 [37]

[A] For processed aggregates, use the nominal maximum size as indicated by the appropriate specification or description. If the specification or description does not indicate a nominal maximum size (for example, a sieve size indicating 90-100% passing), use the maximum size (that sieve indicating 100% passing).

[B] For combined coarse and fine aggregates (for example, base or subbase aggregate), the minimum weight shall be coarse aggregate minimum mass plus 10 kg.

APPENDIXES

(Nonmandatory Information)

X1. SAMPLING AGGREGATE FROM STOCKPILES OR TRANSPORTATION UNITS

X1.1 Scope

X1.1.1 In some situations it is mandatory to sample aggregates that have been stored in stockpiles or loaded into rail cars, barges, or trucks. In such cases the procedure should ensure that segregation does not introduce a serious bias in the results.

X1.2 Sampling from Stockpiles

X1.2.1 In sampling material from stockpiles it is very difficult to ensure unbiased samples, due to the segregation which often occurs when material is stockpiled, with coarser particles rolling to the outside base of the pile. For coarse or mixed coarse and fine aggregate, every effort should be made to enlist the services of power equipment to develop a separate, small sampling pile composed of materials drawn from various levels and locations in the main pile after which several increments may be combined to compose the field sample. If necessary to indicate the degree of variability existing within the main pile, separate samples should be drawn from separate areas of the pile.

X1.2.2 Where power equipment is not available, samples from stockpiles should be made up of at least three increments taken from the top third, at the mid-point, and at the bottom third of the volume of the pile. A board shoved vertically into the pile just above the sampling point aids in preventing further segregation. In sampling stockpiles of fine aggregate the outer layer, which may have become segregated, should be removed and the sample taken from the material beneath. Sampling tubes approximately 30-mm [1.25 in.] min by 2-m [6 ft] min in length may be inserted into the pile at random locations to extract a minimum of five increments of material to form the sample.

X1.3 Sampling from Transportation Units

X1.3.1 In sampling coarse aggregates from railroad cars or barges, effort should be made to enlist the services of power equipment capable of exposing the material at various levels and random locations. Where power equipment is not available, a common procedure requires excavation of three or more trenches across the unit at points that will, from visual appearance, give a reasonable estimate of the characteristics of the load. The trench bottom should be approximately level, at least 0.3 m [1 ft] in width and in depth below the surface. A minimum of three increments from approximately equally spaced points along each trench should be taken by pushing a shovel downward into the material. Coarse aggregate in trucks should be sampled in essentially the same manner as for rail cars or barges, except for adjusting the number of increments according to the size of the truck. For fine aggregate in transportation units, sampling tubes as described in X1.2 may be used to extract an appropriate number of increments to form the sample.

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X2. EXPLORATION OF POTENTIAL AGGREGATE SOURCES

X2.1 Scope

X2.1.1 Sampling for evaluation of potential aggregate sources should be performed by a responsible trained and experienced person. Because of the wide variety of conditions under which sampling may have to be done it is not possible to describe detailed procedures applicable to all circumstances. This appendix is intended to provide general guidance and list more comprehensive references.

X2.2 Sampling Stone from Quarries or Ledges

X2.2.1 *Inspection*—The ledge or quarry face should be inspected to determine discernible variations or strata. Differences in color and structure should be recorded.

X2.2.2 *Sampling and Size of Sample*—Separate samples having a mass of at least 25 kg [55 lbs] should be obtained from each discernible stratum. The sample should not include material weathered to such an extent that it is no longer suitable for the purpose intended. One or more pieces in each sample should be at least 150 by 150 by 100 mm [6 in. by 6 in. by 4 in.] in size with the bedding plane plainly marked, and this piece should be free of seams or fractures.

X2.2.3 *Record*—In addition to the general information accompanying all samples the following information should accompany samples taken from ledges or quarry faces:

X2.2.3.1 Approximate quantity available. (If quantity is very large this may be recorded as practically unlimited.)

X2.2.3.2 Quantity and character of overburden.

X2.2.3.3 A detailed record showing boundaries and location of material represented by each sample.

NOTE X2.1—A sketch, plan, and elevation, showing the thickness and location of the different layers is recommended for this purpose.

X2.3 Sampling Roadside or Bank Run Sand and Gravel Deposits

X2.3.1 *Inspection*—Potential sources of bank run sand and gravel may include previously worked pits from which there is an exposed face or potential deposits discovered through air-photo interpretation, geophysical exploration, or other types of terrain investigation.

X2.3.2 *Sampling*—Samples should be so chosen from each different stratum in the deposit discernible to the sampler. An estimate of the quantity of the different materials should be made. If the deposit is worked as an open-face bank or pit, samples should be taken by channeling the face vertically, bottom to top, so as to represent the materials proposed for use. Overburdened or disturbed material should not be included in the sample. Test holes should be excavated or drilled at numerous locations in the deposit to determine the quality of the material and the extent of the deposit beyond the exposed face, if any. The number and depth of test holes will depend upon the quantity of the material needed, topography of the area, nature of the deposit, character of the material, and potential value of the material in the deposit. If visual inspection indicates that there is considerable variation in the material, individual samples should be selected from the material in each well defined stratum. Each sample should be thoroughly mixed and quartered if necessary so that the field sample thus obtained will be at least 12 kg [25 lbs] for sand and 35 kg [75 lbs] if the deposit contains an appreciable amount of coarse aggregate.

X2.3.3 *Record*—In addition to the general information accompanying all samples the following information should accompany samples of bank run sand and gravel:

X2.3.3.1 Location of supply.

X2.3.3.2 Estimate of approximate quantity available.

X2.3.3.3 Quantity and character of overburden.

X2.3.3.4 Length of haul to proposed site of work.

X2.3.3.5 Character of haul (kind of road, maximum grades, and so forth)

X2.3.3.6 Details as to extent and location of material represented by each sample.

NOTE X2.2—A sketch of plans and elevations, showing the thickness and location of different layers, is recommended for this purpose.

X3. NUMBER AND SIZE OF INCREMENTS NEEDED TO ESTIMATE CHARACTER OF UNIT SAMPLED

X3.1 Scope

X3.1.1 This appendix presents the rationale used by the responsible committee in the development of this practice.

X3.2 Descriptions of Terms Specific to This Standard

X3.2.1 *field sample*—a quantity of the material to be tested of sufficient size to provide an acceptable estimate of the average quality of a unit.

X3.2.2 *lot*—a sizable isolated quantity of bulk material from a single source, assumed to have been produced by the same process (for example, a day's production or a specific mass or volume).

X3.2.3 *test portion*—a quantity of the material of sufficient size extracted from the larger field sample by a procedure designed to ensure accurate representation of the field sample, and thus of the unit sampled.

X3.2.4 *unit*—a batch or finite subdivision of a lot of bulk material (for example, a truck load or a specific area covered).

X3.3 Test Unit, Size, and Variability

X3.3.1 The unit to be represented by a single field sample should neither be so large as to mask the effects of significant variability within the unit nor be so small as to be affected by the inherent variability between small portions of any bulk material.

X3.3.2 A unit of bulk material composed of graded aggregate or aggregate mixtures might consist of a full truckload. If it were possible, the entire load might be tested; as a practical

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matter, a field sample is composed of three or more increments chosen at random from the material as it is loaded or unloaded from the truck. Research has shown that such a procedure permits an acceptable estimate to be made of the average gradation that might be measured from 15 or 20 increments from the truck.

X3.3.3 Significant variability with a lot of material, where it might exist, should be indicated by statistical measures, such as the standard deviation between units selected at random from within the lot.

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Standard Method of Test for

Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

AASHTO Designation: T 11-05 (2009)[1]
ASTM Designation: C 117-04

1. SCOPE

1.1. This test method covers determination of the amount of material finer than a 75-µm (No. 200) sieve in aggregate by washing. Clay particles and other aggregate particles that are dispersed by the wash water, as well as water-soluble materials, will be removed from the aggregate during the test.

1.2. Two procedures are included, one using only water for the washing operation, and the other including a wetting agent to assist the loosening of the material finer than the 75-µm (No. 200) sieve from the coarser material. Unless otherwise specified, Procedure A (water only) shall be used.

1.3. The values stated in SI units are to be regarded as the standard.

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

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 27, Sieve Analysis of Fine and Coarse Aggregates
- T 248, Reducing Samples of Aggregate to Testing Size

2.2. *ASTM Standards*:

- C 117, Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

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3. SUMMARY OF METHOD

3.1. A sample of the aggregate is washed in a prescribed manner, using either plain water or water containing a wetting agent, as specified. The decanted wash water, containing suspended and dissolved material, is passed through a 75-µm (No. 200) sieve. The loss in mass resulting from the wash treatment is calculated as mass percent of the original sample and is reported as the percentage of material finer than a 75-µm (No. 200) sieve by washing.

4. SIGNIFICANCE AND USE

4.1. Material finer than the 75-µm (No. 200) sieve can be separated from larger particles much more efficiently and completely by wet sieving than through the use of dry sieving. Therefore, when accurate determinations of material finer than 75 µm in fine or coarse aggregate are desired, this test method is used on the sample prior to dry sieving in accordance with T 27. The results of this test method are included in the calculation in T 27, and the total amount of material finer than 75 µm by washing, plus that obtained by dry sieving the same sample, is reported with the results of T 27. Usually the additional amount of material finer than 75 µm obtained in the dry-sieving process is a small amount. If it is large, the efficiency of the washing operation should be checked. A large amount of material could also be an indication of the degradation of the aggregate.

4.2. Plain water is adequate to separate the material finer than 75 µm from the coarser material with most aggregates. In some cases, the finer material is adhering to the larger particles, such as some clay coatings and coatings on aggregates that have been extracted from bituminous mixtures. In these cases, the fine material will be separated more readily with a wetting agent in the water.

5. APPARATUS AND MATERIALS

5.1. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

5.2. *Sieves*—A nest of two sieves, the lower being a 75-µm (No. 200) sieve and the upper being a sieve with openings in the range of 2.36-mm (No. 8) to 1.18-mm (No. 16), both conforming to the requirement of M 92.

5.3. *Container*—A pan or vessel of a size sufficient to contain the sample covered with water and to permit vigorous agitation without loss of any part of the sample or water.

5.4. *Oven*—An oven of sufficient size, capable of maintaining a uniform temperature of 110 ± 5°C (230 ± 9°F).

5.5. *Wetting Agent*—Any dispersing agent, such as liquid dishwashing detergents, that will promote separation of the fine materials.

Note 1—The use of a mechanical apparatus to perform the washing operation is not precluded, provided the results are consistent with those obtained using manual operations. The use of some mechanical washing equipment with some samples may cause degradation of the sample.

6. SAMPLING

6.1. Sample the aggregate in accordance with T 2. If the same test sample is to be tested for sieve analysis according to T 27, comply with the applicable requirements of that method.

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6.2. Thoroughly mix the sample of aggregate to be tested and reduce the quantity to an amount suitable for testing using the applicable methods described in T 248. If the same test sample is to be tested according to T 27, the minimum mass shall be as described in the applicable sections of that method. Otherwise, the mass of the test sample, after drying, shall conform with the following:

Nominal Maximum Size	Minimum Mass, g
4.75 mm (No. 4) or smaller	300
9.5 mm ($^3/_8$ in.)	1000
19.0 mm ($^3/_4$ in.)	2500
37.5 mm ($1^1/_2$ in.) or larger	5000

The test sample shall be the end result of the reduction. Reduction to an exact predetermined mass shall not be permitted. If the nominal maximum size of the aggregate to be tested is not listed above, the next larger size listed shall be used to determine sample size.

7. SELECTION OF PROCEDURE

7.1. Procedure A shall be used, unless otherwise specified by the specification with which the test results are to be compared, or when directed by the agency for which the work is performed.

8. PROCEDURE A—WASHING WITH PLAIN WATER

8.1. Dry the test sample to constant mass at a temperature of 110 ± 5°C (230 ± 9°F). Determine the mass to the nearest 0.1 percent of the mass of the test sample.

8.2. If the applicable specification requires that the amount passing the 75-µm (No. 200) sieve shall be determined on a portion of the sample passing a sieve smaller than the nominal maximum size of the aggregate, separate the sample on the designated sieve and determine the mass of the material passing the designated sieve to 0.1 percent of the mass of this portion of the test sample. Use this mass as the original dry mass of the test sample in Section 10.1.

Note 2—Some specifications for aggregates with a nominal maximum size of 50 mm or greater, for example, provide a limit for material passing the 75-µm (No. 200) sieve determined on that portion of the sample passing the 25.0-mm sieve. Such procedures are necessary since it is impractical to wash samples of the size required when the same test sample is to be used for sieve analysis by T 27.

8.3. After drying and determining the mass, place the test sample in the container and add sufficient water to cover it. No detergent, dispersing agent, or other substance shall be added to the water. Agitate the sample with sufficient vigor to result in complete separation of all particles finer than the 75-µm (No. 200) sieve from the coarser particles, and to bring the fine material into suspension. The use of a large spoon or other similar tool to stir and agitate the aggregate in the wash water has been found satisfactory. Immediately pour the wash water containing the suspended and dissolved solids over the nested sieves, arranged with the coarser sieve on top. Take care to avoid, as much as feasible, the decantation of coarser particles of the sample.

8.4. Add a second charge of water to the sample in the container, agitate, and decant as before. Repeat this operation until the wash water is clear.

Note 3—If mechanical washing equipment is used, the charging of water, agitating, and decanting may be a continuous operation.

Note 4—A spray nozzle or a piece of rubber tubing attached to a water faucet may be used to rinse any of the material that may have fallen onto the sieves. The velocity of water, which may be

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increased by pinching the tubing or by use of a nozzle, should not be sufficient to cause any splashing of the sample over the sides of the sieve.

8.5. Return all material retained on the nested sieves by flushing to the washed sample. Dry the washed aggregate to constant mass at a temperature of 110 ± 5°C (230 ± 9°F) and determine the mass to the nearest 0.1 percent of the original mass of the sample.

Note 5—Following the washing of the sample and flushing any materials retained on the 75-µm (No. 200) sieve back into the container, no water should be decanted from the container except through the 75-µm sieve, to avoid loss of material. Excess water from flushing should be evaporated from the sample in the drying process.

9. PROCEDURE B—WASHING USING A WETTING AGENT

9.1. Prepare the sample in the same manner as for Procedure A.

9.2. After drying and determining the mass, place the test sample in the container. Add sufficient water to cover the sample, and add wetting agent to the water (Note 6). Agitate the sample with sufficient vigor to result in complete separation of all particles finer than the 75-µm (No. 200) sieve from the coarser particles, and to bring the fine material into suspension. The use of a large spoon or other similar tool to stir and agitate the aggregate in the wash water has been found satisfactory. Immediately pour the wash water containing the suspended and dissolved solids over the nested sieves, arranged with the coarser sieve on top. Take care to avoid, as much as feasible, the decantation of coarser particles of the sample.

Note 6—There should be enough wetting agent to produce a small amount of suds when the sample is agitated. The quantity will depend on the hardness of the water and the quality of the detergent. Excessive suds may overflow the sieves and carry some material with them.

9.3. Add a second charge of water (without wetting agent) to the sample in the container, agitate, and decant as before. Repeat this operation until the wash water is clear.

9.4. Complete the test as for Procedure A.

10. CALCULATION

10.1. Calculate the amount of material passing a 75-µm (No. 200) sieve by washing as follows:

$$A = \left[(B - C) / B \right] \times 100 \qquad (1)$$

where:

A = percentage of material finer than a 75-µm (No. 200) sieve by washing;

B = original dry mass of sample, g; and

C = dry mass of sample after washing, g.

11. REPORT

11.1. Report the percentage of material finer than the 75-µm (No. 200) sieve by washing to the nearest 0.1 percent, except if the result is 10 percent or more, report the percentage to the nearest whole number.

11.2. Include a statement as to which procedure was used.

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12. PRECISION AND BIAS

12.1. *Precision*—The estimates of precision of this test method listed in Table 1 are based on results from the AASHTO Materials Reference Laboratory Proficiency Sample Program, with testing conducted by this test method and ASTM C 117. The significant differences between the methods at the time the data were acquired is that T 11 required, and ASTM C 117 prohibited, the use of a wetting agent. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories.

Table 1—Precision

	Standard Deviation (1s),[a] percent	Acceptable Range of Two Results (d2s),[a] percent
Coarse aggregate:[b]		
Single-operator precision	0.10	0.28
Multilaboratory precision	0.22	0.62
Fine aggregate:[c]		
Single-operator precision	0.15	0.43
Multilaboratory precision	0.29	0.82

[a] These numbers represent the (1s) and (d2s) limits as described in ASTM C 670.

[b] Precision estimates are based on aggregates having a nominal maximum size of 19.0 mm ($^3/_4$ in.) with less than 1.5 percent finer than the 75-µm (No. 200) sieve.

[c] Precision estimates are based on fine aggregates having 1.0 to 3.0 percent finer than the 75-µm (No. 200) sieve.

12.1.1. The precision values for fine aggregate in Table 1 are based on nominal 500-g test samples. Revision of this test method in 1996 permits the fine aggregate test sample size to 300-g minimum. Analysis of results of testing of 300-g and 500-g test samples from Aggregate Proficiency Test Samples 99 and 100 (Samples 99 and 100 were essentially identical) produced the precision values in Table 2, which indicates only minor differences due to test sample size.

Table 2—Precision Data for 300-g and 500-g Test Samples

Fine Aggregate Proficiency Sample				Within Laboratory		Between Laboratory	
Test Result	Sample Size	No. Labs	Avg	1s	d2s	1s	d2s
AASHTO T 11/ASTM C 117 (Total material passing the	500 g	270	1.23	0.08	0.24	0.23	0.66
No. 200 sieve by washing, percent)	300 g	264	1.20	0.10	0.29	0.24	0.68

Note 7—The values for fine aggregate in Table 1 will be revised to reflect the 300-g test sample size when a sufficient number of Aggregate Proficiency Tests have been conducted using that sample size to provide reliable data.

12.2. *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in this test method, no statement on bias is made.

13. KEYWORDS

13.1. Aggregate; size analysis; wash loss; 75µm (No. 200) sieve.

[1] Except for Sections 5.1 and 6.2, and Note 4, this test method is identical with ASTM C 117-04.

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Standard Method of Test for

Sieve Analysis of Fine and Coarse Aggregates

AASHTO Designation: T 27-11[1]
ASTM Designation: C 136-06

1. SCOPE

1.1. This method covers the determination of the particle size distribution of fine and coarse aggregates by sieving.

1.2. Some specifications for aggregates, which reference this method, contain grading requirements including both coarse and fine fractions. Instructions are included for sieve analysis of such aggregates.

1.3. The values stated in SI units are to be regarded as the standard. The values in parentheses are provided for information purposes only.

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

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 248, Reducing Samples of Aggregate to Testing Size

2.2. *ASTM Standards*:

- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

2.3. *IEEE/ASTM Standard*:

- SI 10, American National Standard for Use of the International System of Units (SI): The Modern Metric System

3. TERMINOLOGY

3.1. *Definitions*—For definitions of terms used in this standard, refer to ASTM C 125.

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4. SUMMARY OF METHOD

4.1. A sample of dry aggregate of known mass is separated through a series of sieves of progressively smaller openings for determination of particle size distribution.

5. SIGNIFICANCE AND USE

5.1. This method is used primarily to determine the grading of materials proposed for use as aggregates or being used as aggregates. The results are used to determine compliance of the particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates. The data may also be useful in developing relationships concerning porosity and packing.

5.2. Accurate determination of material finer than the 75-µm (No. 200) sieve cannot be achieved by use of this method alone. Test Method T 11 for material finer than the 75-µm (No. 200) sieve by washing should be employed.

6. APPARATUS

6.1. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

6.2. *Sieves*—The sieve cloth shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sieving. The sieve cloth and standard sieve frames shall conform to the requirements of M 92. Nonstandard sieve frames shall conform to the requirements of M 92 as applicable.

Note 1—It is recommended that sieves mounted in frames larger than standard 203.2 mm (8 in.) diameter be used for testing coarse aggregate to reduce the possibility of overloading the sieves. See Section 8.3.

6.3. *Mechanical Sieve Shaker*—A mechanical sieving device, if used, shall create motion of the sieves to cause the particles to bounce, tumble, or otherwise turn so as to present different orientations to the sieving surface. The sieving action shall be such that the criterion for adequacy of sieving described in Section 8.4 is met in a reasonable time period.

Note 2—Use of a mechanical sieve shaker is recommended when the size of the sample is 20 kg (44 lb) or greater, and may be used for smaller samples, including fine aggregate. Excessive time (more than approximately 10 minutes) to achieve adequate sieving may result in degradation of the sample. The same mechanical sieve shaker may not be practical for all sizes of samples, since the large sieving area needed for practical sieving of a large nominal size coarse aggregate very likely could result in loss of a portion of the sample if used for a smaller sample of coarse aggregate or fine aggregate.

6.4. *Oven*—An oven of appropriate size capable of maintaining a uniform temperature of 110 ± 5°C (230 ± 9°F).

7. SAMPLING

7.1. Sample the aggregate in accordance with T 2. The mass of the field sample shall be the mass shown in T 2 or four times the mass required in Sections 7.4 and 7.5 (except as modified in Section 7.6), whichever is greater.

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7.2. Thoroughly mix the sample and reduce it to an amount suitable for testing using the applicable procedures described in T 248. The sample for test shall be the approximate mass desired when dry and shall be the end result of the reduction. Reduction to an exact predetermined mass shall not be permitted.

Note 3—Where sieve analysis, including determination of material finer than the 75-µm (No. 200) sieve, is the only testing proposed, the size of the sample may be reduced in the field to avoid shipping excessive quantities of extra material to the laboratory.

7.3. *Fine Aggregate*—The size of the test sample of aggregate, after drying, shall be 300 g minimum.

7.4. *Coarse Aggregate*—The mass of the test sample of coarse aggregate shall conform with the following:

Nominal Maximum Size Square Openings, mm (in.)	Minimum Mass of Test Sample, kg (lb)
9.5 ($^3/_8$)	1 (2)
12.5 ($^1/_2$)	2 (4)
19.0 ($^3/_4$)	5 (11)
25.0 (1)	10 (22)
37.5 ($1^1/_2$)	15 (33)
50 (2)	20 (44)
63 ($2^1/_2$)	35 (77)
75 (3)	60 (130)
90 ($3^1/_2$)	100 (220)
100 (4)	150 (330)
125 (5)	300 (660)

7.5. *Coarse and Fine Aggregates Mixtures*—The mass of the test sample of coarse and fine aggregate mixtures shall be the same as for coarse aggregate in Section 7.4.

7.6. *Samples of Large-Size Coarse Aggregate*—The size of sample required for aggregate with 50-mm (2-in.) nominal maximum size or larger is such as to preclude convenient sample reduction and testing as a unit except with large mechanical splitters and sieve shakers. As an option when such equipment is not available, instead of combining and mixing sample increments and then reducing the field sample to testing size, conduct the sieve analysis on a number of approximately equal sample increments such that the total mass tested conforms to the requirements of Section 7.4.

7.7. In the event that the amount of material finer than the 75-µm (No. 200) sieve is to be determined by T 11, use the procedure described in Section 7.7.1 or 7.7.2, whichever is applicable.

7.7.1. For aggregates with a nominal maximum size of 12.5 mm ($^1/_2$ in.) or less, use the same test sample for testing by T 11 and this method. First test the sample in accordance with T 11 through the final drying operation, then dry sieve the sample as stipulated in Sections 8.2 through 8.6 of this method.

7.7.2. For aggregates with a nominal maximum size greater than 12.5 mm ($^1/_2$ in.), a single test sample may be used as described in Section 7.7.1 or separate test samples may be used for T 11 and this method.

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7.7.3. Where the specification requires determination of the total amount of material finer than the 75-µm (No. 200) sieve by washing and dry sieving, use the procedure described in Section 7.7.1.

8. PROCEDURE

8.1. If the test sample has not been subjected to testing by T 11, dry it to constant mass at a temperature of 110 ± 5°C (230 ± 9°F) and determine the mass of it to the nearest 0.1 percent of the total original dry sample mass.

Note 4—For control purposes, particularly where rapid results are desired, it is generally not necessary to dry coarse aggregate for the sieve analysis test. The results are little affected by the moisture content unless (1) the nominal maximum size is smaller than about 12.5 mm ($^1/_2$ in.), (2) the coarse aggregate contains appreciable material finer than 4.75 mm (No. 4), or (3) the coarse aggregate is highly absorptive (a lightweight aggregate, for example). Also, samples may be dried at the higher temperature associated with the use of hot plates without affecting results, provided steam escapes without generating pressures sufficient to fracture the particles, and temperatures are not so great as to cause chemical breakdown of the aggregate.

8.2. Select sieves with suitable openings to furnish the information required by the specifications covering the material to be tested. Use additional sieves as desired or necessary to provide other information, such as fineness modulus, or to regulate the amount of material on a sieve. Nest the sieves in order of decreasing size of opening from top to bottom and place the sample, or portion of the sample if it is to be sieved in more than one increment, on the top sieve. Agitate the sieves by hand or by mechanical apparatus for a sufficient period, established by trial or checked by measurement on the actual test sample, to meet the criterion for adequacy of sieving described in Section 8.4.

8.3. Limit the quantity of material on a given sieve so that all particles have opportunity to reach sieve openings a number of times during the sieving operation. For sieves with openings smaller than 4.75-mm (No. 4), the quantity retained on any sieve at the completion of the sieving operation shall not exceed 7 kg/m^2 (4 g/in.^{2}) of sieving surface area (Note 5). For sieves with openings 4.75 mm (No. 4) and larger, the quantity retained in kg shall not exceed the product of 2.5 × (sieve opening, mm × (effective sieving area, m^2)). This quantity is shown in Table 1 for five sieve-frame dimensions in common use. In no case shall the quantity retained be so great as to cause permanent deformation of the sieve cloth.

8.3.1. Prevent an overload of material on an individual sieve by one or a combination of the following methods:

8.3.1.1. Insert an additional sieve with opening size intermediate between the sieve that may be overloaded and the sieve immediately above that sieve in the original set of sieves.

8.3.1.2. Split the sample into two or more portions, sieving each portion individually. Combine the masses of the several portions retained on a specific sieve before calculating the percentage of the sample on the sieve.

8.3.1.3. Use sieves having a larger frame size and providing greater sieving area.

Note 5—The 7 kg/m^2 amounts to 200 g for the usual 203.2-mm (8-in.) diameter sieve (with effective sieving surface diameter of 190.5 mm (7.5 in.)).

8.3.1.4. In the case of coarse and fine aggregate mixtures, the portion of the sample finer than the 4.75-mm (No. 4) sieve may be distributed among two or more sets of sieves to prevent overloading of individual sieves.

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8.3.1.5. Alternatively, the portion finer than the 4.75-mm (No. 4) sieve may be reduced in size using a mechanical splitter according to T 248. If this procedure is followed, compute the mass of each size increment of the original sample as follows:

$$A = \frac{W_1}{W_2} \times B \qquad (1)$$

where:

A = mass of size increment on total sample basis,

W_1 = mass of fraction finer than 4.75-mm (No. 4) sieve in total sample,

W_2 = mass of reduced portion of material finer than 4.75-mm (No. 4) sieve actually sieved, and

B = mass of size increment in reduced portion sieved.

Table 1—Maximum Allowable Quantity of Material Retained on a Sieve, kg

Sieve Opening Size	Nominal Dimensions of Sieve[a]				
	203.2-mm, dia[b]	254-mm, dia[b]	304.8-mm, dia[b]	350 by 350, mm	372 by 580, mm
	Sieving Area, m^2				
	0.0285	0.0457	0.0670	0.1225	0.2158
125 mm (5 in.)	[c]	[c]	[c]	[c]	67.4
100 mm (4 in.)	[c]	[c]	[c]	30.6	53.9
90 mm (3 1/2 in.)	[c]	[c]	15.1	27.6	48.5
75 mm (3 in.)	[c]	8.6	12.6	23.0	40.5
63 mm (2 1/2 in.)	[c]	7.2	10.6	19.3	34.0
50 mm (2 in.)	3.6	5.7	8.4	15.3	27.0
37.5 mm (1 1/2 in.)	2.7	4.3	6.3	11.5	20.2
25.0 mm (1 in.)	1.8	2.9	4.2	7.7	13.5
19.0 mm (3/4 in.)	1.4	2.2	3.2	5.8	10.2
12.5 mm (1/2 in.)	0.89	1.4	2.1	3.8	6.7
9.5 mm (3/8 in.)	0.67	1.1	1.6	2.9	5.1
4.75 mm (No. 4)	0.33	0.54	0.80	1.5	2.6

[a] Sieve frame dimensions in inch units: 8.0-in. diameter; 10.0-in. diameter; 12.0-in. diameter; 13.8 by 13.8 in. (14 by 14 in. nominal); 14.6 by 22.8 in. (16 by 24 in. nominal).

[b] The sieve area for round sieves is based on an effective diameter 12.7 mm (1/2 in.) less than the nominal frame diameter, because M 92 permits the sealer between the sieve cloth and the frame to extend 6.35 mm (1/4 in.) over the sieve cloth. Thus the effective sieving diameter for a 203.2-mm (8.0-in.) diameter sieve frame is 190.5 mm (7.5 in.). Sieves produced by some manufacturers do not infringe on the sieve cloth by the full 6.35 mm (1/4 in.).

[c] Sieves indicated have less than five full openings and should not be used for sieve testing.

8.4. Continue sieving for a sufficient period and in such manner that, after completion, not more than 0.5 percent by mass of the total sample passes any sieve during 1 minute of continuous hand sieving performed as follows: Hold the individual sieve, provided with a snug-fitting pan and cover, in a slightly inclined position in one hand. Strike the side of the sieve sharply and with an upward motion against the heel of the other hand at the rate of about 150 times per minute, turn the sieve about one-sixth of a revolution at intervals of about 25 strokes. In determining sufficiency of sieving for sizes larger than the 4.75-mm (No. 4) sieve, limit the material on the sieve to a single layer of particles. If the size of the mounted testing sieves makes the described sieving motion impractical, use 203.2-mm (8-in.) diameter sieves to verify the sufficiency of sieving.

8.5. Unless a mechanical sieve shaker is used, hand sieve particles obtained on the 75 mm (3 in.) by determining the smallest sieve opening through which each particle will pass by rotating the particles, if necessary, in order to determine whether they will pass through a particular opening; however, do not force particles to pass through an opening.

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8.6. Determine the mass of each size increment on a scale or balance conforming to the requirements specified in Section 6.1 to the nearest 0.1 percent of the total original dry sample mass. The total mass of the material after sieving should check closely with the original mass of sample placed on the sieves. If the amounts differ by more than 0.3 percent, based on the original dry sample mass, the results should not be used for acceptance purposes.

9. CALCULATION

9.1. Calculate percentages passing, total percentages retained, or percentages in various size fractions to the nearest 0.1 percent on the basis of the total mass of the initial dry sample. If the same test sample was first tested by T 11, include the mass of material finer than 75-µm (No. 200) sieve by washing in the sieve analysis calculation; and use the total dry sample mass prior to washing in T 11 as the basis for calculating all the percentages.

9.1.1. When sample increments are tested as provided in Section 7.6, total the masses of the portion of the increments retained on each sieve, and use these masses to calculate the percentage as in Section 9.1.

9.2. Calculate the fineness modulus, when required, by adding the total percentages of material in the sample that is coarser than each of the following sieves (cumulative percentages retained), and dividing the sum by 100; 150 µm (No. 100), 300 µm (No. 50), 600 µm (No. 30), 1.18 mm (No. 16), 2.36 mm (No. 8), 4.75 mm (No. 4), 9.5 mm ($^3/_8$ in.), 19.0 mm ($^3/_4$ in.), 37.5 mm ($1^1/_2$ in.), and larger, increasing the ratio of 2 to 1.

10. REPORT

10.1. Depending upon the form of the specifications for use of the material under test, the report shall include one of the following:

10.1.1. Total percentage of material passing each sieve, or

10.1.2. Total percentage of material retained on each sieve, or

10.1.3. Percentage of material retained between consecutive sieves.

10.2. Report percentages to the nearest whole number, except if the percentage passing the 75-µm (No. 200) sieve is less than 10 percent, it shall be reported to the nearest 0.1 percent.

10.3. Report the fineness modulus, when required, to the nearest 0.01.

11. PRECISION AND BIAS

11.1. *Precision*—The estimates of precision for this test method are listed in Table 2. The estimates are based on the results from the AASHTO Materials Reference Laboratory Proficiency Sample Program, with testing conducted by T 27 and ASTM C 136. The data are based on the analyses of the test results from 65 to 233 laboratories that tested 18 pairs of coarse aggregate proficiency test samples and test results from 74 to 222 laboratories that tested 17 pairs of fine aggregate proficiency test samples (Samples No. 21 through 90). The values in the table are given for different ranges of total percentage of aggregate passing a sieve.

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Table 2—Estimates of Precision

	Total Percentage of Material Passing		Standard Deviation (1s), Percent[a]	Acceptable Range of Two Results (d2s), Percent[a]
Coarse Aggregate:[b]	100	≥95	0.32	0.9
Single-operator precision	<95	≥85	0.81	2.3
	<85	≥80	1.34	3.8
	<80	≥60	2.25	6.4
	<60	≥20	1.32	3.7
	<20	≥15	0.95	2.7
	<15	≥10	1.00	2.8
	<10	≥5	0.75	2.1
	<5	≥2	0.53	1.5
	<2	0	0.27	0.8
Multilaboratory precision	100	≥95	0.35	1.0
	<95	≥85	1.37	3.9
	<85	≥80	1.92	5.4
	<80	≥60	2.82	8.0
	<60	≥20	1.97	5.6
	<20	≥15	1.60	4.5
	<15	≥10	1.48	4.2
	<10	≥5	1.22	3.4
	<5	≥2	1.04	3.0
	<2	0	0.45	1.3
Fine Aggregate:				
Single-operator precision	100	≥95	0.26	0.7
	<95	≥60	0.55	1.6
	<60	≥20	0.83	2.4
	<20	≥15	0.54	1.5
	<15	≥10	0.36	1.0
	<10	≥2	0.37	1.1
	<2	0	0.14	0.4
Multilaboratory precision	100	≥95	0.23	0.6
	<95	≥60	0.77	2.2
	<60	≥20	1.41	4.0
	<20	≥15	1.10	3.1
	<15	≥10	0.73	2.1
	<10	≥2	0.65	1.8
	<2	0	0.31	0.9

[a] These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670.

[b] The precision estimates are based on aggregates with nominal maximum size of 19.0 mm (3/4 in.).

11.1.1. The precision values for Fine Aggregate in Table 2 are based on nominal 500-g test samples. Revision of ASTM C 136 in 1994 permitted the fine aggregate test sample size to be 300 g minimum. Analysis of results of testing of 300-g and 500-g test samples from Aggregate Proficiency Test Samples 99 and 100 (Samples 99 and 100 were essentially identical) produced the precision values in Table 3, which indicate only minor differences due to test sample size.

Note 6—The values for Fine Aggregate in Table 2 will be revised to reflect the 300-g test sample size when a sufficient number of Aggregate Proficiency Tests have been conducted using that sample size to provide reliable data.

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Table 3—Precision Data for 300-g and 500-g Fine Aggregate Test Samples

Fine Aggregate Proficiency Sample				Within Laboratory		Among Laboratories	
Test Result	Sample Size	Number of Labs	Average	1s	d2s	1s	d2s
AASHTO T 27/ASTM C 136:							
Total material passing the 4.75-mm (No. 4) sieve (%)	500 g	285	99.992	0.027	0.066	0.037	0.104
	300 g	276	99.990	0.021	0.060	0.042	0.117
Total material passing the 2.36-mm (No. 8) sieve (%)	500 g	281	84.10	0.43	1.21	0.63	1.76
	300 g	274	84.32	0.39	1.09	0.69	1.92
Total material passing the 1.18-mm (No. 16) sieve (%)	500 g	286	70.11	0.53	1.49	0.75	2.10
	300 g	272	70.00	0.62	1.74	0.76	2.12
Total material passing the 600-µm (No. 30) sieve (%)	500 g	287	48.54	0.75	2.10	1.33	3.73
	300 g	276	48.44	0.87	2.44	1.36	3.79
Total material passing the 300-µm (No. 50) sieve (%)	500 g	286	13.52	0.42	1.17	0.98	2.73
	300 g	275	13.51	0.45	1.25	0.99	2.76
Total material passing the 150-µm (No. 100) sieve (%)	500 g	287	2.55	0.15	0.42	0.37	1.03
	300 g	270	2.52	0.18	0.52	0.32	0.89
Total material passing the 75-µm (No. 200) sieve (%)	500 g	278	1.32	0.11	0.32	0.31	0.85
	300 g	266	1.30	0.14	0.39	0.31	0.85

11.2. *Bias*—Since there is no accepted reference material suitable for determining the bias in this test method, no statement on bias is made.

[1] Similar but not identical to ASTM C 136-06.

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Standard Method of Test for

Mechanical Analysis of Extracted Aggregate

AASHTO Designation: T 30-10

1. SCOPE

1.1. This method covers a procedure for the determination of the particle-size distribution of fine and coarse aggregates extracted from hot mix asphalt (HMA), using sieves with square openings.

1.2. The values stated in SI units are to be regarded as the standard.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 164, Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)
- T 255, Total Evaporable Moisture Content of Aggregate by Drying
- T 308, Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method

2.2. *ASTM Standard*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. SIGNIFICANCE AND USE

3.1. This method is used to determine the grading of aggregates extracted from HMA. The results are used to determine compliance of the particle-size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregates to be used in HMA.

4. APPARATUS

4.1. The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass or better, and conform to M 231.

4.2. *Sieves*—The sieve cloth shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sieving. The sieve cloth and standard sieve frames shall conform to the requirements of M 92. Nonstandard sieve frames shall conform to the requirements of M 92 as applicable.

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4.3. *Mechanical Sieve Shaker*—A mechanical sieving device, if used, shall create motion of the sieves to cause the particles to bounce, tumble, or otherwise turn so as to present different orientations to the sieving surface. The sieving action shall be such that the criterion for adequacy of sieving described in Section 6.7 is met in a reasonable time period.

Note 1—Use of a mechanical sieve shaker is recommended when the size of the sample is 20 kg (44 lb) or greater, and may be used for smaller samples, including fine aggregate. Excessive time (more than approximately 10 min) to achieve adequate sieving may result in degradation of the sample. The same mechanical sieve shaker may not be practical for all sizes of samples, since the large sieving area needed for practical sieving of a large nominal size coarse aggregate very likely could result in loss of a portion of the sample if used for a smaller size of coarse aggregate or fine aggregate.

4.4. *Oven*—An oven of sufficient size, capable of maintaining a uniform temperature of 110 ± 5°C (230 ± 9°F).

4.5. *Wetting Agent*—Any dispersing agent, such as Calgon, Joy, or other detergent that will promote separation of the fine materials.

4.6. *Containers and Utensils*—A pan or vessel of a size sufficient to contain the sample covered with water and to permit vigorous agitation without loss of any part of the sample or water.

5. SAMPLE

5.1. The sample shall consist of the entire lot or sample of aggregate obtained according to T 164 or T 308 from which the binder material has been extracted.

6. PROCEDURE

6.1. *Sample*:

6.1.1. The sample shall be dried, if necessary, until further drying at 110 ± 5°C (230 ± 9°F) does not alter the mass by more than 0.1 percent, the precision of weighing. The total mass of aggregate in the HMA being tested is the sum of the mass of the dried aggregates and the mineral matter contained in the extracted asphalt binder. The latter is to be taken as the sum of the mass of ash in the extract and the increase in mass of the filter element as determined in T 164.

6.1.2. Determine and record the mass of the sample to the nearest 0.1 g. This mass shall agree with the mass of aggregate remaining after ignition (M_f from T 308) within 0.1 percent of M_f for an aggregate sample obtained from T 308. If the variation exceeds 0.1 percent, the results of this test should not be used for acceptance purposes.

6.2. The test sample shall be placed in a container and covered with water. Add a sufficient amount of wetting agent to assure a thorough separation of the material finer than the 75-µm (No. 200) sieve from the coarser particles. There should be enough wetting agent to produce a small amount of suds when the sample is agitated. The quantity will depend on the hardness of the water, the quality of the detergent, and the agitation process. Excessive suds may overflow the sieves and carry some material with them. The contents of the container shall be agitated vigorously and the wash water immediately poured over a nest of two sieves consisting of a 2.00- or 1.18-mm (No. 10 or No. 16) sieve superimposed on a 75-µm (No. 200) sieve. The use of a large spoon to stir and agitate the aggregate in the wash water has been found to be satisfactory.

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The use of a mechanical apparatus to perform the washing operation is allowable, providing mechanical wash does not degrade the sample. When mechanical washing equipment is used, the introduction of water, agitating, and decanting may be a continuous operation. Use care not to overflow or overload the 75-µm (No. 200) sieve.

6.3. The agitation shall be sufficiently vigorous to result in the complete separation of all particles finer than the 75-µm (No. 200) sieve from the coarse particles and bring them into suspension in order that they may be removed by decantation of the wash water. Care should be taken to avoid, as much as possible, the decantation of the coarse particles of the sample. The operation shall be repeated until the wash water is clear.

6.4. All material retained on the nested sieves shall be returned to the container. The washed aggregate in the container shall be dried to constant mass per T 255, and weighed to the nearest 0.1 percent.

6.5. The aggregate shall then be sieved over sieves of various sizes required by the specification covering the HMA, including the 75-µm (No. 200) sieve. Nest the sieves in order of decreasing size of opening from top to bottom and place the sample on the top sieve. Agitate the sieves by a mechanical apparatus for a sufficient period, established by trial or checked by measurement on the actual test sample, to meet the criterion for adequacy of sieving described in Section 6.7.

6.6. Limit the quantity of material on a given sieve so that all particles have opportunity to reach sieve openings a number of times during the sieving operation. For sieves with openings smaller than 4.75 mm (No. 4), the mass retained on any sieve at the completion of the sieving operation shall not exceed 6 kg/m^2 (4 g/in.^{2}) of sieving surface. For sieves with openings 4.75 mm (No. 4) and larger, the mass in kg shall not exceed the product of 2.5 × (sieve opening in mm) × (the sieving surface area in m^2). In no case shall the mass be so great as to cause permanent deformation of the sieve cloth.

Note 2—The 6 kg/m^2 (4 g/in.^{2}) amounts to 200 g for the usual 203-mm (8-in.) diameter sieve. The amount of material retained on a sieve may be regulated by (1) the introduction of a sieve with larger openings immediately above the given sieve or (2) testing the sample in a number of increments.

6.7. Continue sieving for a sufficient period and in such manner that, after completion, not more than 0.5 percent by mass of the total sample passes any sieve during 60 s of continuous hand-sieving performed as follows: Hold the individual sieve, provided with a snug-fitting pan and cover, in a slightly inclined position in one hand. Strike the side of the sieve sharply and with an upward motion against the heel of the other hand at the rate of about 150 times per minute, turning the sieve about one sixth of a revolution at intervals of about 25 strokes. In determining the adequacy of sieving for sizes larger than the 4.75-mm (No. 4) sieve, limit the material on the sieve to a single layer of particles. If the size of the mounted testing sieves makes the described sieving motion impractical, use 203-mm (8-in.) diameter sieves to verify the adequacy of sieving.

7. CALCULATIONS

7.1. The mass of material passing each sieve and retained on the next and the amount passing the 75-µm (No. 200) sieve shall be recorded. The summation of these various masses must check the dried mass after washing within 0.2 percent of the total mass. The mass of dry material passing the 75-µm (No. 200) sieve by dry sieving shall be added to the mass removed by washing, and if applicable, the mass of mineral matter in the asphalt binder, in order to obtain the total passing the 75-µm (No. 200) sieve. The masses of fractions retained on the various sieves and the total passing the 75-µm (No. 200) sieve shall be converted to percentages by dividing each by the total mass of aggregate in the HMA from Section 6.1.

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7.2. For aggregate samples obtained from T 308, apply the aggregate correction factor, as required in T 308, to obtain the final total passing percentages.

8. REPORT

8.1. The results of the sieve analysis shall be reported as follows: (a) total percentages passing each sieve; or (b) total percentages retained on each sieve; or (c) percentages retained between consecutive sieves, depending upon the form of the specifications for the use of the material being tested. Percentages shall be reported to the nearest whole number, except for the percentage passing the 75-µm (No. 200) sieve, which shall be reported to the nearest 0.1 percent.

9. PRECISION AND BIAS

9.1. *Precision*—The estimates of precision for this test method are listed in Table 1. The estimates are based on the results from the AASHTO Materials Reference Laboratory Proficiency Sample Program, with testing conducted by T 30. The data are based on the analyses of the test results from 47 to 190 laboratories that tested 17 pairs of proficiency test samples (Samples No. 1 through 34). The values in the table are given for different ranges of total percentage of aggregate passing a sieve.

Table 1—Precision

	Total Percentage of Material Passing a Sieve	Standard Deviation (1s) Percent[a]	Acceptable Range of Two Results—(d2s) Percent[a]
Extracted aggregate:[b]			
Single-Operator Precision	95 to 100	0.49	1.4
	40 to 94	1.06	3.0
	25 to 39	0.65	1.8
	10 to 24	0.46	1.3
	5to 9	0.29	0.8
	2 to 4	0.21	0.6
	0 to 1	0.17	0.5
Multilaboratory Precision	95 to 100	0.57	1.6
	40 to 94	1.24	3.5
	25 to 39	0.84	2.4
	10 to 24	0.81	2.3
	5 to 9	0.56	1.6
	2 to 4	0.43	1.2
	0 to 1	0.32	0.9

[a] These numbers represent, respectively, the (1s) and (d2s) limits described in ASTM C 670.

[b] The precision estimates are based on aggregates with nominal maximum sizes of 19.0 mm ($^3/_4$ in.) to 9.5 mm ($^3/_8$ in.).

9.2. *Bias*—This test method has no bias since the values determined can only be defined in terms of this test method.

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Standard Method of Test for

Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)

AASHTO Designation: T 164-11[1]
ASTM Designation: D 2172-05

1. SCOPE

1.1. These methods cover the quantitative determination of asphalt binder in hot mix asphalt (HMA) and HMA pavement samples. Aggregate obtained by these methods may be used for sieve analysis using T 30.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific hazards are given in Section 8.

Note 1—The results obtained by these methods may be affected by the age of the material tested, with older samples tending to yield slightly lower asphalt binder contents. Best quantitative results are obtained when the test is made on HMA mixtures and pavements shortly after their preparation. It is difficult to remove all the asphalt binder when some aggregates are used; some solvent may remain within the mineral matter affecting the measured asphalt binder content.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- R 59, Recovery of Asphalt Binder from Solution by Abson Method
- T 30, Mechanical Analysis of Extracted Aggregate
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 110, Moisture or Volatile Distillates in Hot Mix Asphalt (HMA)
- T 168, Sampling Bituminous Paving Mixtures
- T 228, Specific Gravity of Semi-Solid Asphalt Materials
- T 329, Moisture Content of Hot Mix Asphalt (HMA) by Oven Method

2.2. *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D 604, Standard Specification for Diatomaceous Silica Pigment (Withdrawn 2003)

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- D 2111, Standard Test Methods for Specific Gravity and Density of Halogenated Organic Solvents and Their Admixtures
- D 4080, Standard Specification for Trichloroethylene, Technical and Vapor-Degreasing Grade
- D 6368, Standard Specification for Vapor-Degreasing Solvents Based on *normal*-Propyl Bromide and Technical Grade *normal*-Propyl Bromide

3. TERMINOLOGY

3.1. *nominal maximum size (of aggregate)*—One size larger than the first sieve that retains more than 10 percent aggregate.

3.2. *constant mass*—shall be defined as the mass at which further drying does not alter the mass by more than 0.05 percent when weighed at 2-h intervals.

4. SUMMARY OF TEST METHODS

4.1. The HMA is extracted with trichloroethylene, *normal*-propyl bromide, or methylene chloride, using the extraction equipment applicable to the particular method. Terpene extractant may be used in Method A or E. The asphalt binder content is calculated by differences from the mass of the extracted aggregate, moisture content, and mineral matter in the extract. The asphalt binder content is expressed as a mass percent of moisture-free mixtures.

5. SIGNIFICANCE AND USE

5.1. All of the methods can be used for quantitative determinations of asphalt binder in HMA mixtures and pavement samples for specification acceptance, service evaluation, quality control, and research. Each method prescribes the solvents and any other reagents that can be used in the method. R 59 requires that Method A or E (Note 2) and reagent grade trichloroethylene be used when asphalt binder is recovered from solution.

Note 2—The vacuum extractor, Section 22.1.1, can be modified by a vacuum trap attached to the top of the "end point" sight tube to collect the extract to allow its use for recoveries (Figure 4b).

6. APPARATUS

6.1. *Oven*—capable of maintaining the temperature at 110 ± 5°C (230 ± 9°F), for warming the sample.

6.2. *Oven*—capable of maintaining the temperature at 149 to 163°C (300 to 325°F), for drying the sample if the moisture content is not determined.

6.3. *Pan*—flat, of appropriate size.

6.4. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass or better, and conform to the requirements of M 231.

6.5. *Cylinders*—graduated, 1000 or 2000-mL capacity.

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7. REAGENTS

7.1. *Methylene Chloride*, technical grade. *Caution*—see Section 8.

7.2. *Normal-Propyl Bromide*, conforming to ASTM D 6368—see Section 8.

7.3. *Trichloroethylene*, reagent grade (Note 3) or conforming to ASTM D 4080—see Section 8.

7.4. *Terpene*—Extractant, shall be non-halogenated, non-toxic, and shall readily dissolve asphalt binder from HMA and place it into solution. This extractant shall be easily rinsed from the remaining aggregate without forming a gel, and the extractant rinsed from the aggregate shall pass readily through the diatomaceous earth and the filter.

7.5. When asphalt binder is intended to be extracted and then tested for additional properties, a reagent grade solvent must be used (Note 3).

Note 3—Non-reagent grade solvents may contain epoxy resins which may affect the properties of the recovered binder. In particular, certain acid modified binders may be affected by non-reagent grade solvents.

Note 4—Only vented ovens should be used when terpene extractants are used.

8. PRECAUTIONS

8.1. The solvents listed in Section 7 should be used only under a hood or with an effective surface exhaust system in a well-ventilated area, since they are all toxic to some degree as described in R 16. Trichloroethylene, methylene chloride, and *normal*-propyl bromide in the presence of heat and moisture may form acids that are extremely corrosive to certain metals, particularly when subject to contact over lengthy periods of time. Proper precautions should be taken to not allow these solvents to remain in small quantities in the effluent tanks of aluminum vacuum extractors.

8.2. Trichloroethylene stored in a steel container and in continuous contact with moisture may decompose by dehydrohalogenation to form unsaturated hydrocarbon liquids and hydrogen chloride. Steel drums containing trichloroethylene should be stored in a cool, dry location, kept tightly sealed and opened as infrequently as possible. Trichloroethylene should be transferred from the drums to clean, dry, brown glass bottles for laboratory use. The hydrogen chloride in decomposed trichloroethylene may harden an asphalt during the extraction and Abson recovery test (R 59).

8.3. All local, state, and federal regulations must be followed with when hauling, using, storing, and discarding extractants and rinse water. These requirements include fire ordinances as well as wastewater treatment regulations. The Materials Safety Data Sheet should be followed closely to avoid fires and explosions. Storage of extractant-soaked rags should be prohibited.

9. SAMPLING

9.1. Obtain samples in accordance with T 168.

9.2. *Preparation of Test Specimens*:

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9.2.1. If the HMA is not sufficiently soft to separate with a spatula or trowel, place it in a large, flat pan, and warm it in a 110 ± 5°C (230 ± 9°F) oven only until it can be handled or separated. Split or quarter the material until the mass of material required for the test is obtained.

9.2.2. The size of the test sample shall be governed by the nominal maximum aggregate size of the HMA and conform to the mass requirement shown in Table 1 (Note 5).

Table 1—Size of Sample

Nominal Maximum Aggregate Size		Minimum Mass of Sample, kg
mm	in.	
4.75	No. 4	0.5
9.5	$^3/_8$ in.	1
12.5	$^1/_2$ in.	1.5
19.0	$^3/_4$ in.	2
25.0	1 in.	3
37.5	$1^1/_2$ in.	4

Note 5—When the mass of the test specimen exceeds the capacity of the equipment used (for a particular method), the test specimen may be divided into suitable increments, tested, and the results appropriately combined for calculation of asphalt binder content (Section 13).

9.2.3. Unless the HMA sample is free of moisture (Note 7), a test specimen is required for the determination of moisture (Section 10) in the HMA. Take this test specimen from the remaining sample in the HMA immediately after obtaining the extraction test specimen.

Note 6—If the extraction test is only being performed to recover asphalt binder from the HMA and the percent asphalt binder is not being determined, it is unnecessary to determine the moisture content of the HMA.

Table 2—Dimensional Equivalents

mm	in.	mm	in.	mm	in.
0.8	$^1/_{32}$	42.9	$1^{11}/_{16}$	155.6	$6^1/_8$
1.6	$^1/_{16}$	44.5	$1^3/_4$	157.2	$6^3/_{16}$
2.0	$^5/_{64}$	47.6	$1^7/_8$	158.8	$6^1/_4$
3.2	$^1/_8$	50.8	2	163.5	$6^7/_{16}$
4.0	$^5/_{32}$	55.6	$2^3/_{16}$	165.1	$6^1/_2$
4.8	$^3/_{16}$	56.4	$2^7/_{32}$	187.3	$7^3/_8$
5.6	$^7/_{32}$	57.2	$2^1/_4$	203.2	8
6.4	$^1/_4$	58.7	$2^5/_{16}$	247.7	$9^3/_4$
7.9	$^5/_{16}$	63.5	$2^1/_2$	254.0	10
9.5	$^3/_8$	66.7	$2^5/_8$	257.2	$10^1/_8$
12.7	$^1/_2$	71.4	$2^{13}/_{16}$	260.4	$10^1/_4$
15.9	$^5/_8$	76.2	3	279.4	11
19.1	$^3/_4$	88.9	$3^1/_2$	304.8	12
25.4	1	95.3	$3^3/_4$	320.7	$12^5/_8$
28.6	$1^1/_8$	101.6	4	330.2	13
30.2	$1^3/_{16}$	108.0	$4^1/_4$	342.9	$13^1/_2$
35.7	$1^{13}/_{32}$	127.0	5	355.6	14
38.1	$1^1/_2$	138.1	$5^7/_{16}$	368.3	$14^1/_2$
40.5	$1^{19}/_{32}$	149.2	$5^7/_8$	384.2	$15^1/_8$
41.3	$1^5/_8$	152.4	6	393.7	$15^1/_2$
47.6	$1^7/_8$	154.8	$6^3/_{32}$	406.4	16
0.9 mm	20 gauge	3.2 mm	#8 B&S	26 qt	24.6 L
1.2 mm	18 gauge	4.75 mm	No. 4 mesh		

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10. MOISTURE CONTENT

10.1. When required, determine the moisture content of the mixture (Section 9.2.3) in accordance with the procedure described in T 110 or T 329.

Note 7—If recovery of asphalt binder from the solution obtained from the extraction test is not required, the entire test specimen may be dried in an oven at a temperature of 105 to 165°C (221 to 329°F) to constant mass prior to extraction, instead of determining the moisture content.

10.2. Calculate the mass of water (W_2, Section 13) in the extraction test portion by multiplying mass percent water (Section 10.1) by the mass of the extraction test portion (W_1, Section 13).

TEST METHOD A

11. APPARATUS

11.1. In addition to the apparatus listed in Section 6, the following apparatus is required for Method A:

11.1.1. *Extraction Apparatus*, consisting of a bowl approximating that shown in Figure 1 and an apparatus in which the bowl may be revolved at controlled variable speeds up to 3600 r/min. The speed may be controlled manually or with a preset speed control. The apparatus should be provided with a container for catching the solvent discharged from the bowl and a drain for removing the solvent. The apparatus preferably shall be provided with explosion-proof features and installed in a hood or an effective surface exhaust system to provide ventilation.

Note 8—Similar apparatus of larger size may be used.

11.1.2. *Filter Rings*, felt or paper, to fit the rim of the bowl.

11.1.3. *Low-Ash Paper Filter Rings* may be used in place of the felt filter ring (Section 11.1.2). Such filter rings shall consist of low-ash filter paper stock, 1.27 ± 0.13 mm (0.05 ± 0.005 in.) thick. The nominal base weight of the paper shall be 150 ± 14 kg (330 ± 30 lb) for a ream [500 sheets, 635 by 965 mm (25 by 38 in.)]. The ash content of the paper should not exceed 0.2 percent (approximately 0.034 g per ring).

Note 9—Where terpene extractants are used, the gears and shaft should be lubricated frequently.

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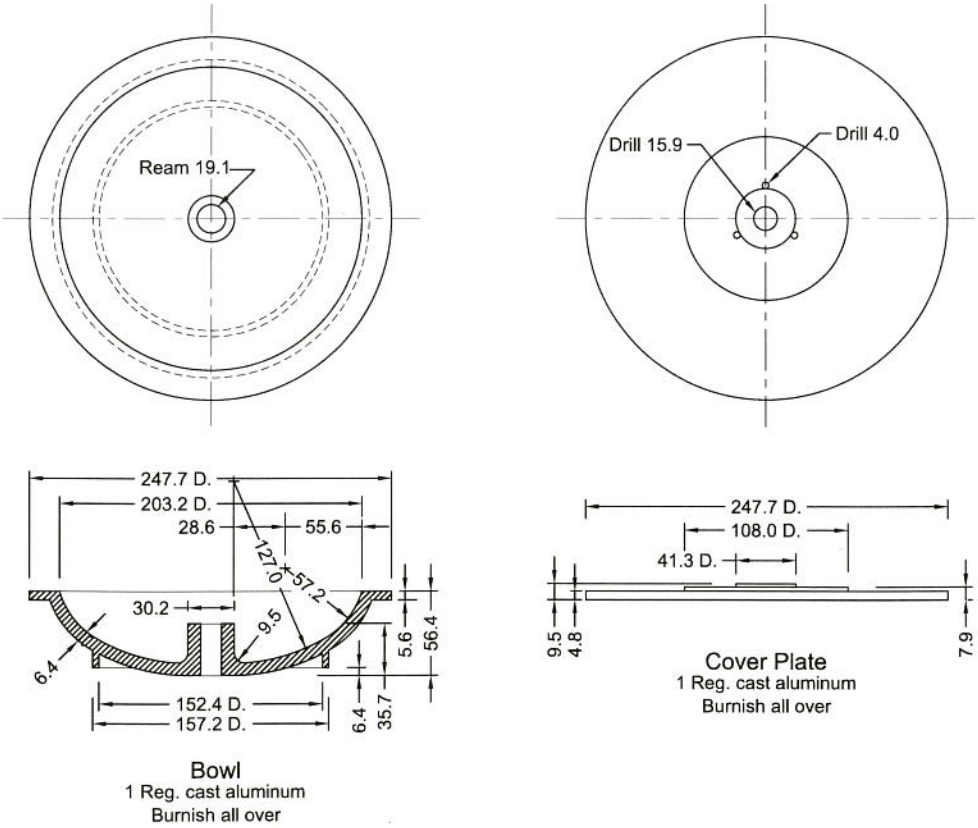

Note: See Table 2 for dimensional equivalents. All dimensions shown in millimeters unless otherwise noted.

Figure 1—Extraction Unit Bowl (Method A)

12. PROCEDURE

12.1. Determine the moisture content of the material in accordance with Section 10.

12.2. Place the test portion into a bowl.

12.3. Cover the test portion in the bowl with trichloroethylene, methylene chloride, *normal*-propyl bromide, or terpene extractant, and allow sufficient time for the solvent to disintegrate the test portion (not more than 1 h). Place the bowl containing the test portion and the solvent in the extraction apparatus. Dry the filter ring to a constant mass in an oven at 110 ± 5°C (230 ± 9°F), and fit it around the edge of the bowl. Clamp the cover on the bowl tightly, and place an appropriate container under the drain to collect the extract.

12.4. Start the centrifuge revolving slowly, and gradually increase the speed to a maximum of 3600 r/min until solvent ceases to flow from the drain. Allow the machine to stop; add 200 mL (or more as appropriate for the mass of the sample) of trichloroethylene, methylene chloride, *normal*-propyl bromide, or terpene extractant, and repeat the procedure. Use sufficient solvent additions (not less than three) until the extract is not darker than a light straw color. Collect the extract and the washings in an appropriate container for mineral matter determination.

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12.5. Carefully transfer the filter ring and all of the aggregate in the centrifuge bowl into a tared metal pan. Dry in air under a hood until the fumes dissipate, and then to a constant mass in an oven at 110 ± 5°C (230 ± 9°F) (Notes 10 and 11). The mass of the extracted aggregate (W_3) is equal to the mass of the contents in the pan minus the initial dry mass of the filter ring. Brush off mineral matter adhering to the surface of the filter ring, and add it to the extracted aggregate for further testing.

Note 10—The filter and aggregate may be left inside the centrifuge bowl and dried to constant mass in an oven at 110 ± 5°C (230 ± 9°F) and the mass determined.

Note 11—The filter ring may be dried separately to constant mass in an oven at 110 ± 5°C (230 ± 9°F) provided that care is taken not to lose any of the fine material clinging to the filter. If this procedure is used, the aggregate may then be dried to constant mass either in an oven or on a hot plate at 110 ± 5°C (230 ± 9°F).

12.5.1. Use the following alternative procedure when low-ash filter rings are used. Place the aggregate and filter rings in a clean metal pan. Dry as specified above. Carefully fold the dried filter ring and stand it on the aggregate. Burn the filter ring. Determine the mass of the extracted aggregate in the pan (W_3).

Note 12—Since dry aggregate absorbs moisture when exposed to air containing moisture, determine the mass of the extracted aggregate immediately after cooling to a suitable temperature.

12.6. Determine the amount of mineral matter in the extract by one of the procedures specified in Annex A1.

13. CALCULATION OF ASPHALT BINDER CONTENT

$$\textit{Asphalt Binder Content},\ \% = \frac{(W_1 - W_2) - (W_3 + W_4)}{W_1 - W_2} \times 100 \qquad (1)$$

where:

W_1 = mass of test portion;

W_2 = mass of water in test portion;

W_3 = mass of extracted mineral aggregate; and

W_4 = mass of mineral matter in the extract.

Note 13—When ashless filter rings are not used, add the increase in mass of the felt ring to W_4.

Note 14—When it is desired to express the asphalt binder content as a mass percent of the moisture-free aggregate, substitute the mass $W_3 + W_4$ for the mass $W_1 - W_2$ in the divisor of Equation 1.

TEST METHOD B

14. APPARATUS

14.1. In addition to the apparatus listed in Section 6, the following apparatus is required for Test Method B:

14.1.1. *Extraction Apparatus*—similar to that shown in Figure 2.

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Figure 2—Extraction Apparatus (Method B)

14.1.1.1. *Glass Jar*—cylindrical, plain, made of heat-resistant glass. The jar shall be free of cracks, scratches, or other evidence of flaws that might cause breakage during heating.

14.1.1.2. *Cylindrical Metal Frames*—one or two. The lower frame shall have legs of sufficient length to support the frame, including the apex of the metal cone and paper cone liner above the solvent level. When two frames are used, the upper frame shall have legs of sufficient length to support the metal cone and paper cone liner at or above the top rim of the lower frame. The legs of the upper frame shall fit securely in the top rim of the lower frame. A bail handle may be provided on the inside of the top rim of each frame for convenient handling. The metal used in fabricating the frames shall be essentially unreactive to the solvents used in the test.

14.1.1.3. *Condenser*—fabricated with a truncated hemispherical condensing surface and a truncated conical top. Other suitable geometric shapes may also be used provided they accomplish the condensing and flow functions intended. The material used in fabricating the condenser shall be essentially unreactive to water and to the solvent used and shall be provided with a suitable water inlet and outlet.

14.1.1.4. *Filter Paper*—medium-grade, fast-filtering. The diameter of the paper shall be such that when folded in accordance with the directions given below, it shall completely line the metal cones in the frames.

14.1.1.5. *Thermal Distributing Protective Pad*—approximately 3 mm (0.1 in.) thick for use as insulation between the glass jar and hot plates.

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14.1.1.6. *Electric Hot Plate*—thermostatically controlled, of sufficient dimensions and heat capacity to permit refluxing of the solvent as described in Section 16.2.5.

15. PREPARATION OF TEST PORTION

15.1. Prepare a test portion for moisture determination and extraction in accordance with the procedure described in Section 9.

16. PROCEDURE

16.1. *Moisture*:

16.1.1. Determine the moisture content of the HMA (Section 9.2.3) in accordance with the method described in Section 10.

16.2. *Extraction*:

16.2.1. Dry one sheet of filter paper for each frame used to a constant mass in an oven at 110 ± 5°C (230 ± 9°F). Fold each paper on its diameter; fold the ends over, and spread it open to form a proper size to fit inside the metal cones.

16.2.2. Determine the mass of each frame with its filter paper liner to the nearest 0.5 g. Record the mass of each frame.

16.2.3. Place the test portion in the frame(s). If two frames are used, distribute the test portion approximately equally between the two. The top of the test portion must be below the upper edge of the paper liner. Determine the mass of each loaded frame separately to the nearest 0.5 g. Again, record the mass.

16.2.4. Use one of the solvents (Note 15) specified in Section 7.1, 7.2, or 7.3. Pour the solvent into the glass cylinder, and place the bottom frame into it. The solvent level should be below the apex of the one in the lower frame. If two frames are used, place the upper frame in the lower frame, fitting its legs into the holes in the upper rim of the lower frame.

Note 15—Sufficient denatured ethyl alcohol may be poured over the test portion(s) to wet the filter paper. A mixture of 20 percent denatured alcohol and 80 percent trichloroethylene has proven to be a better solvent for some aggregates.

16.2.5. If required, place the thermal insulating pad on the hot plate and then the cylinder on the pad. Cover the condenser. Circulate a gentle, steady stream of cool water through the condenser. Adjust the temperature of the hot plate so that the solvent will boil gently and a steady stream of condensed solvent flows into the cone. If necessary, adjust the temperature of the hot plate to maintain the solvent stream at a rate necessary to keep the test portions in the cone(s) completely covered with condensed solvent. Take care not to allow condensed solvent to overflow the filter cone(s). Continue the refluxing until the solvent flowing from the lower cone is a light straw color (when viewed against a white background). At this point, turn off the hot plate, and allow the apparatus to cool enough to handle; turn off the condenser, and remove it from the cylinder.

16.2.6. Remove the frame assembly from the cylinder. Allow it to dry in air (hood), and then dry it to a constant mass in an oven at 110 ± 5°C (230 ± 9°F) (Note 9).

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16.2.7. Determine the mineral matter in the extraction solution by one of the procedures specified in Annex A1.

17. CALCULATION OF ASPHALT BINDER CONTENT

17.1. Calculate the percentage of asphalt binder in the test portion in accordance with the procedure described in Section 13.

TEST METHOD D

18. APPARATUS

18.1. In addition to the apparatus listed in Section 6, the following apparatus is required for Test Method D:

18.1.1. *Extraction Apparatus*—As shown in Figure 3, consisting of an extraction kettle of metal or borosilicate glass, fitted with a perforated basket and a condenser top. The underside of the condenser shall be covered with numerous rounded knobs to distribute the condenser solvent uniformly over the surface of the sample. The suspension of the basket shall be arranged to support the basket 13 mm ($^1/_2$ in.) above the bottom of the kettle, for immersion of the test portion in the solvent, and at least 75 mm (3 in.) above the bottom of the kettle for refluxing (Note 8).

18.1.2. *Cloth Filter Sacks*—with an elastic hem for lining the basket.

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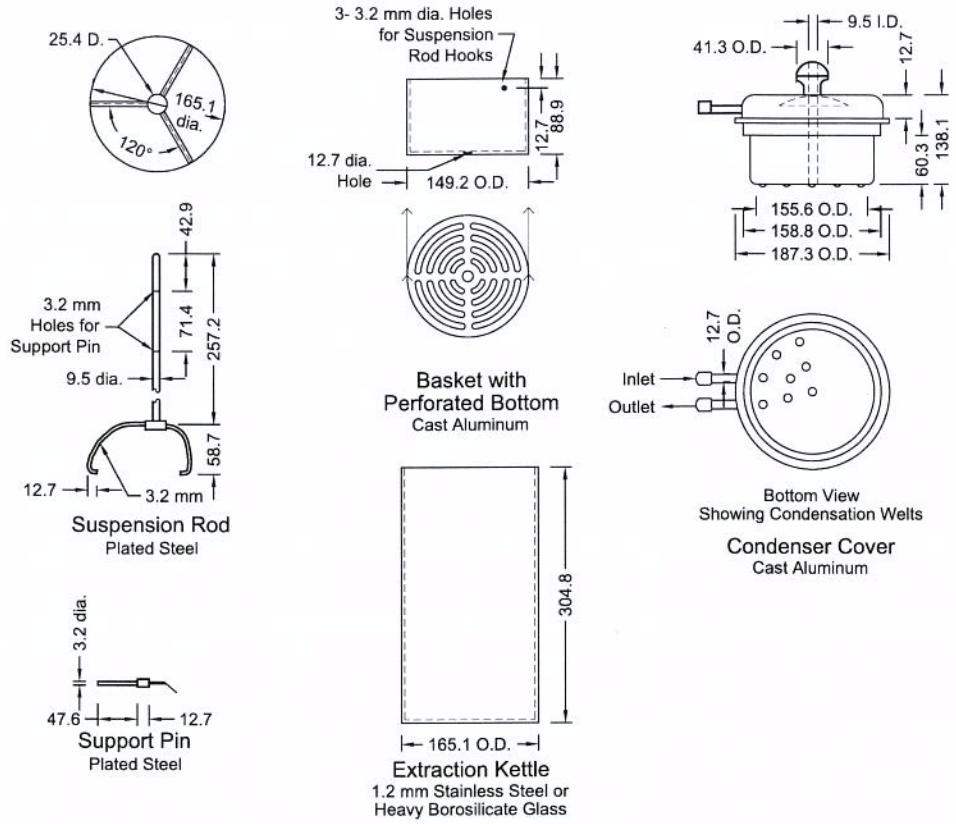

Figure 3—Extractor Unit (Method D)

19. PREPARATION OF TEST PORTIONS

19.1. Prepare test portions for moisture determination and extraction in accordance with the procedure described in Section 9.

20. PROCEDURE

20.1. *Moisture*:

20.1.1. Determine the moisture content of the HMA (Section 9.2.3) in accordance with the method described in Section 10.

20.2. *Extraction*:

20.2.1. Insert a filter sack in the extraction basket, and determine the mass with the tare pan to determine the total tare mass. Place the test portion in the filter sack, and determine the total mass. Calculate the mass of the test portion.

20.2.2. Attach the suspension rod to the loaded basket, and set the assembly into the extraction kettle. Pour approximately 600 mL of solvent (Section 7.1, 7.2, or 7.3) over the test portion. Set the

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condenser cover in place on the kettle. Provide a flow of cold water through the condenser lid. Raise the basket to immersion level, for example 13 mm ($^1/_2$ in.) above the bottom of kettle, by inserting the support pin through the upper hole of the suspension rod. Place the extractor on the hot plate, and adjust the heating rate so that solvent is maintained at a gentle boil, avoiding vigorous boiling which might wash fines over the sides of the basket.

20.2.3. Continue heating with the test portion in the immersion position for 15 to 30 min, and then raise the basket to refluxing level. Increase the heat, and maintain active boiling until solvent dripping from the basket appears to be a light straw color when viewed against a white background. If a stainless steel kettle is used, lift out the basket and the condenser cover assembly for examination of the solvent.

20.2.4. Remove the extractor from the hot plate, and allow it to cool for several minutes. Lift out the basket and condenser assembly. Cover the kettle; remove the filter sack, and distribute its contents into the tared pan in which the mass of the test portion was originally determined. Place the filter sack on top of the recovered aggregate. Dry on a steam bath and then in an oven at 110 ± 5°C (230 ± 9°F) to constant mass. Transfer the extract solution to a 1000-mL graduate. Wash the extractor clean with solvent, and add the washings to the extract solution.

20.2.5. Determine the mineral matter in the extract solution by one of the procedures specified in Annex A1.

21. CALCULATION OF ASPHALT BINDER CONTENT

21.1. Calculate the percentage of asphalt binder in the test portion in accordance with the procedure described in Section 13.

TEST METHOD E

22. APPARATUS

22.1. In addition to the apparatus listed in Section 6, the following apparatus is required for Test Method E:

22.1.1. *Vacuum Extractor*—complete with the vacuum pump, gasket, rubber tubing, filter paper, support plate, and funnel ring. The dimensional equivalents and apparatus shown in Table 3, and Figures 4a, 4b, and 4c and similar designs are suitable.

Table 3—Dimensional Equivalents

in.	mm	in.	mm
16	406	$2^1/_4$	57
$12^5/_8$	321	$1^{19}/_{32}$	40
12	305	$^3/_4$	19
8	203	$^1/_2$	12.7
$6^7/_{16}$	164	$^3/_8$	9.5
$6^1/_4$	159	$^1/_4$	6.4
$6^1/_8$	156	$^3/_{64}$	1.19
$6^3/_{32}$	155	0.060	1.52
$3^3/_4$	95		

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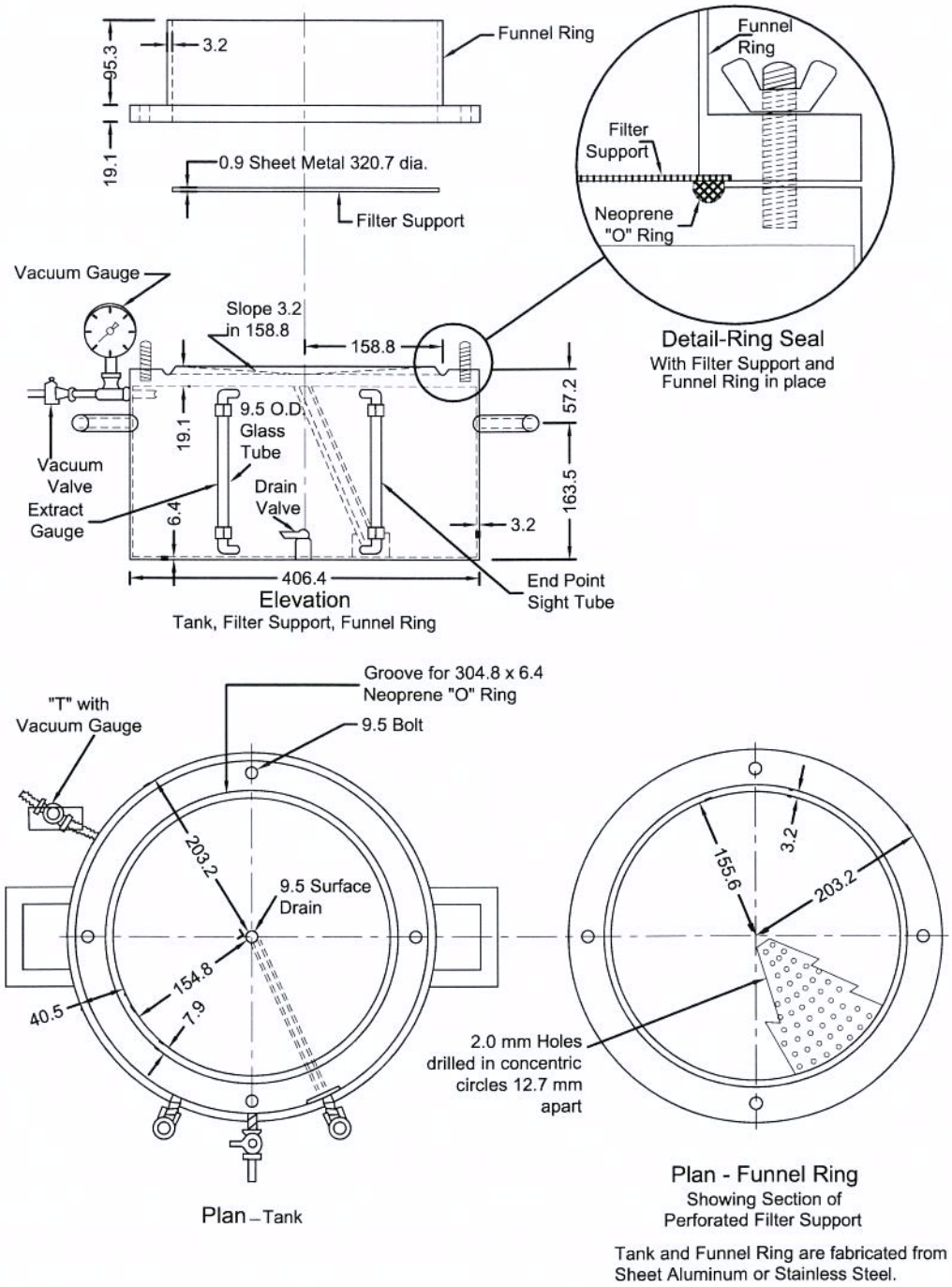

Note: See Table 3 for dimensional equivalents. All dimensions shown in millimeters unless otherwise noted.

Figure 4a—Vacuum Extractor

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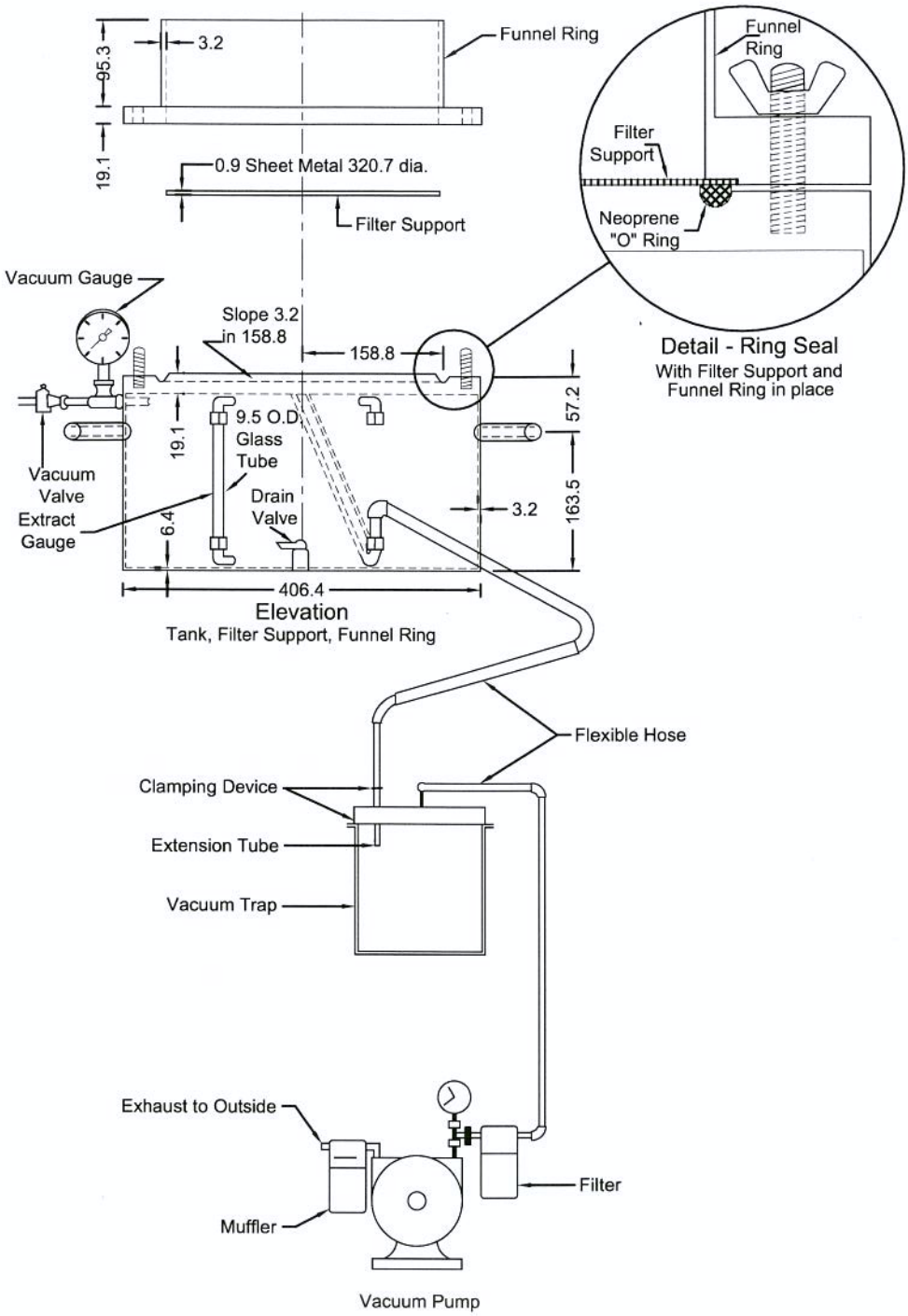

Note: All dimensions are shown in millimeters unless otherwise noted.

Figure 4b—Vacuum Extractor

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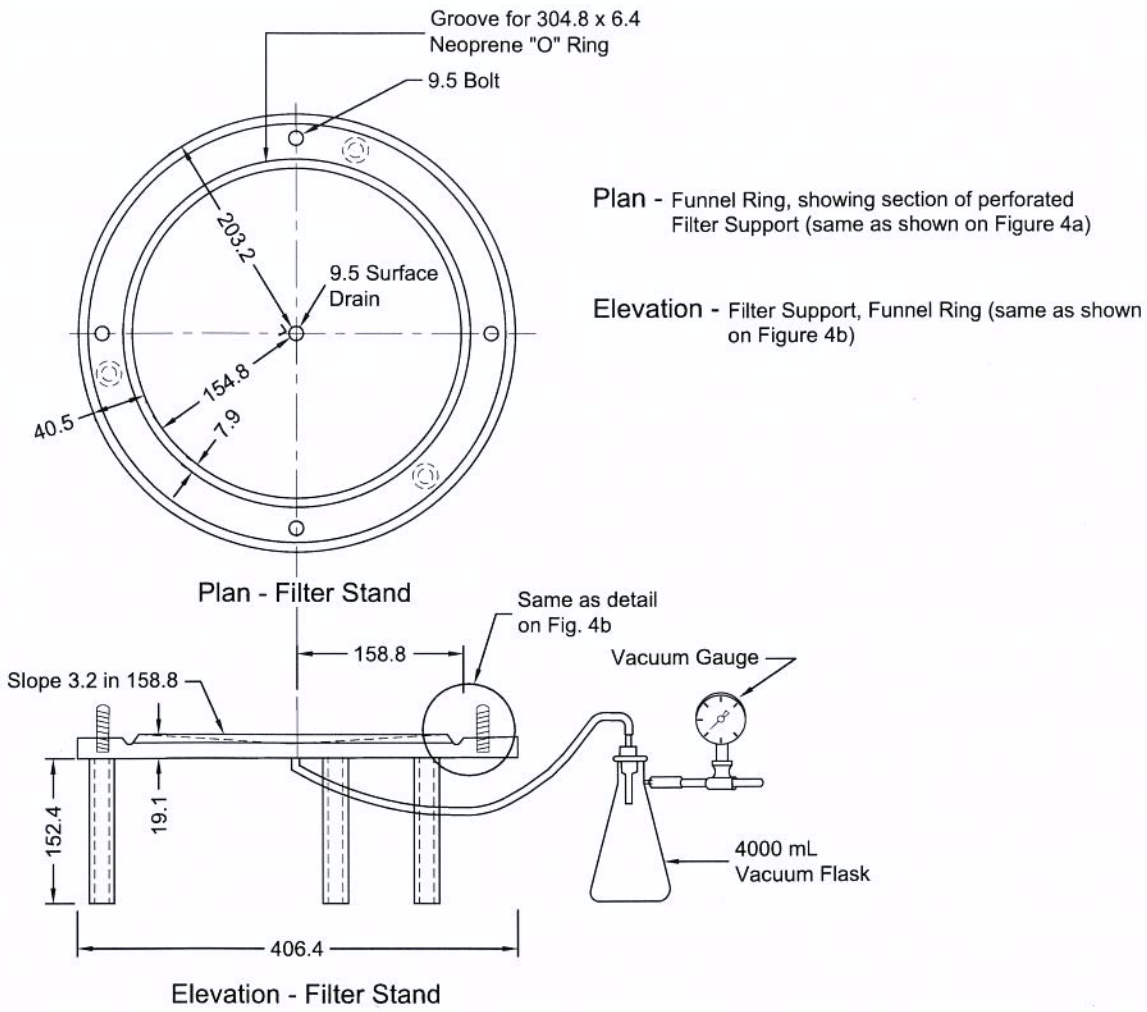

Note: All dimensions are shown in millimeters unless otherwise noted.

Figure 4c—Vacuum Extractor

22.1.2. *Filter Paper*, medium-grade, fast-filtering, 330 mm (13 in.) in diameter.

22.1.3. *Sample Container*, 3.8-L (4-qt) capacity or greater.

22.1.4. *Erlenmeyer Flasks*, glass, two, having a capacity of 4000 mL each.

22.1.5. *Graduate*, glass, having a capacity of 500 mL.

22.1.6. *Wash Bottle*, plastic, having a capacity of 500 mL.

22.1.7. *Dial Thermometer*, having a range from 10 to 82°C (50 to 180°F).

22.1.8. *Mixing Spoon*.

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22.1.9. *Spatula.*

22.1.10. *Stiff Bristled Brush.*

22.1.11. *Erlenmeyer Flask*, glass, having a capacity of 1000 mL.

22.1.12. *Watch Glass*, having a diameter of approximately 100-mm (4-in.).

22.1.13. *Metal Tongs*, 150 to 200 mm (6 to 8 in.) long.

22.1.14. 1.18-mm (No. 16) and 75-µm (No. 200) Sieves, 305 mm (12 in.) in diameter (optional).

Note 16—Use apparatus and materials listed under Sections 22.1.11, 22.1.12, 22.1.13, 23.1, and 23.2 only with HMA that is hard to filter, as in Method E-II.

22.1.15. *Stainless Steel Beaker.*

23. REAGENTS AND MATERIALS

23.1. Diatomaceous Silica Filtering Aid conforming to Type B of ASTM D 604.[2]

23.2. *Ethyl Alcohol*, denatured (optional).

23.3. *Methylene Chloride* (Note 17).

Note 17—Any of the other solvents listed in Section 7 may be substituted for methylene chloride.

24. PREPARATION OF TEST PORTIONS

24.1. Prepare test portions for moisture determination and extraction in accordance with the procedure described in Section 9.

25. PROCEDURE

25.1. Determine the moisture content of the HMA (Section 9.2.3) in accordance with the method described in Section 10.

25.2. *Extraction*:

25.2.1. Place the extraction test portion into the tared stainless steel beaker, and determine the mass (Note 18).

25.2.2. If the test portion is above 54°C (130°F), allow it to cool to a temperature less than 54°C (130°F). When sufficiently cool, pour 200 mL of denatured alcohol, if needed, over the specimen (Note 18). Add approximately 700 mL of extractant, and stir until the asphalt binder is visually in solution (Note 19).

Note 18—Alcohol should not be needed with terpene extractants.

Note 19—If equipment is available, an ultrasonic cleaning tank may be used instead of the beaker (Section 25.2.1) in which to bring the asphalt binder into solution (Section 25.2.2).

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25.2.3. Dry the filter paper (more than one filter paper may be used) to constant mass in an oven at 110 ± 5°C (230 ± 9°F), and place the filter paper on the extractor, taking care to center the filter paper and tighten the wing nuts "finger tight" (Note 20).

Note 20—Experience has shown that clogging of the filter may be reduced by decanting the extract solution through nested 1.18-mm (No. 16) and 75-µm (No. 200) sieves onto the filter. When sieves are used, the solution will be decanted onto the 1.18-mm (No. 16) sieve instead of the filter.

25.2.4. Start the vacuum pump and slowly decant extract solution from the sample container onto the filter. When all solution has been removed from the filter paper, the vacuum pump may be stopped or left running.

25.2.5. Cover the sample remaining in the container with extractant, up to 700 mL. Stir gently until the asphalt binder and aggregate fines appear to be in suspension (or start the ultrasonic cleaner if used). Repeat the step in Section 25.2.4.

25.2.6. Repeat Section 25.2.5 until the solution is a light straw color and the aggregate is visually clean. The flow of solvent may be slowed for color observation by partially opening the vacuum valve and reducing the vacuum. If terpene extractant is used, pour all of the extractant onto the filter, and allow the vacuum to continue until the fluid has passed through the filter. Repeat Sections 25.2.5 and 25.2.4, using water preferably above 43°C (110°F), as many times as necessary to remove the terpene residue from the aggregate and render the rinse water clear. Operate the vacuum pump for a few minutes after the last wash to aid in drying the test portion. Scrape the aggregate away from the side of the funnel ring toward the center of the filter to avoid loss when the ring is removed. Also wash the sides of the funnel ring to remove any fines. Stop the vacuum pump and remove the ring, then brush the clinging aggregate into the tared drying pan. Carefully pick up the filter paper and aggregate by holding the paper on opposite sides and raising it straight up. Transfer the aggregate on the filter paper to the tared drying pan, and brush the clinging aggregate from the filter into the pan. Alternatively, the filter paper and aggregate may be contained separately in tared pans or the aggregate may be contained in a tared pan and the filter paper placed on top of it. In either case, use care to assure that all traces of aggregate in the test sample are transferred to the drying pan(s).

25.2.7. Dry the extracted aggregate and filter to a constant mass in an oven at 110 ± 5°C (230 ± 9°F) (Note 21).

Note 21—See the alternate procedure in Section 12.5.1 when low-ash filter paper is used.

25.2.8. Determine the mass of the filter and aggregate in the pan(s), and record it. Subtract the mass of the filter and pan to determine the mass of the extracted aggregate.

25.2.9. Determine the mineral matter in the extract solution by one of the procedures specified in Annex A1 (Note 22).

Note 22—Sections 25.2.9 and 25.2.15 may be omitted when this method is used only for control of asphalt binder content during HMA production (plant control).

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25.2.10. To extract a slow-filtering HMA mixture efficiently, prepare the test portion as described in Sections 25.2.1 and 25.2.2.

25.2.11. Dry the filter paper to constant mass in an oven at 110 ± 5°C (230 ± 9°F), and place the filter paper on the extractor, taking care to center the filter paper and tighten the wing nuts "finger tight" (Note 20).

25.2.12. Weigh between 50 and 200 g of oven-dried diatomaceous silica filtering aid into a 1000-mL Erlenmeyer flask; record the mass, and then add 500 mL of extractant. Swirl until the diatomaceous silica is completely in suspension.

25.2.13. Immediately pour the diatomaceous silica and extractant over the filter. Two pre-dried filters separated by an additional 50 to 100 g of diatomaceous earth may be used to retain the minus 75-µm (No. 200) material, if desired, to facilitate improved flow of the liquid. Start the vacuum pump, and let it run until the pad formed by the diatomaceous silica is surface dry and begins to crack slightly (Note 23).

Note 23—Some diatomaceous silica may be washed through the filter and included in the mineral matter determination of Section 25.2.15. Blank tests are recommended to determine the amount of diatomaceous silica, if any, lost through the filter. An appropriate correction will be required in the mineral matter mass.

25.2.14. Place the watch glass in the extractor, and slowly decant the extractant from the container over the watch glass (Note 24). Stop the vacuum pump when all the solution has been removed from the filter. Repeat as in Section 25.2.5, except decant the solution onto the watch glass. Complete the procedure as in Section 25.2.6. Also wash the watch glass with extractant to remove any fines onto the filter.

Note 24—When nested sieves are used, the watch glass may be omitted.

25.2.15. Determine the amount of mineral matter in the extract solution by one of the procedures specified in Annex A1 (Note 22).

26. CALCULATION OF ASPHALT BINDER CONTENT (APPLICABLE TO BOTH METHOD E-I AND METHOD E-II)

26.1. Calculate the percentage of asphalt binder in the test portion in accordance with the procedure described in Section 13.

27. PRECISION AND BIAS

27.1. The single-laboratory standard deviation has been found to be 0.18 percent. Therefore, results of two properly conducted tests by the same operator on the same batch should not differ by more than 0.52 percent. These values become 0.21 and 0.58, respectively, when extractant containing 85 percent terpene is used (Notes 25 and 26).

27.2. The multilaboratory standard deviation has been found to be 0.29 percent. Therefore, the results of two properly conducted tests from two different laboratories on samples from the same batch

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should not differ by more than 0.81 percent. These values become 0.29 and 0.83, respectively, when extractant containing 85 percent terpene is used (Notes 25 and 26).

Note 25—These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C 670.

Note 26—These precision statements are based on one pair of reference samples with 59 laboratories participating and three laboratory results deleted as outlying observations. The reference samples contained aggregate with 98 percent passing the 9.5-mm ($^3/_8$-in.) screen. All test methods were used in the interlaboratory test program.

ANNEX

(Mandatory Information)

A1. DETERMINING THE AMOUNT OF MINERAL MATTER IN THE EXTRACT

A1.1. *Ashing Method*:

A1.1.1. *Apparatus*:

A1.1.1.1. *Ignition Dish*—at least 125 mL in capacity.

A1.1.1.2. Ignition Furnace or Bunsen Burner.

A1.1.1.3. Steam bath or hot plate.

A1.1.1.4. Desiccator.

A1.1.1.5. *Analytical Balance*—conforming to the requirements of M 231, Class B.

A1.1.1.6. *Cylinder*—100 mL in capacity.

A1.1.2. *Reagents*:

A1.1.2.1. *Ammonium Carbonate Solution*—Saturated solution of reagent-grade ammonium carbonate [$(NH_4)_2CO_2$]

A1.1.3. *Procedure*:

A1.1.3.1. Determine either the volume or mass of the total extract (W_1). Condition the ignition dish in an ignition furnace or over a bunsen burner; cool it in a desiccator, and determine the mass of the ignition dish to the nearest 0.001 g. Agitate the extract thoroughly, and immediately measure 100 mL or 100 g into the ignition dish. Evaporate to dryness on a steam bath or hot plate. Ash the residue at a dull red heat [500 to 600°C (932 to 1112°F)] and cool it. Determine the mass of the ash, and add 5 mL of saturated ammonium carbonate solution per gram of ash. Digest at room temperature for 1 h. Dry in an oven at 110 ± 5°C (230 ± 9°F) to constant mass; cool in a desiccator, and determine the mass to the nearest 0.001 g (G).

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A1.1.3.2. Calculate the mass of mineral matter in the total volume of extract (W_4) as follows:

$$W_4 = G\,(W_1/100) \qquad (A1.1)$$

where:

G = ash remaining in the ignition dish to nearest 0.001 g; and

W_1 = total volume, mL (or total mass, g) of extract.

A1.2. *Centrifuge Method*:

A1.2.1. *Apparatus*:

A1.2.1.1. Any suitable high-speed (3000 r/min or higher) centrifuge of the continuous-flow type.[3]

A1.2.1.2. *Balance*—conforming to the requirements of M 231, Class G 1.

A1.2.1.3. Funnel or Steam Hood.

A1.2.2. *Procedure*:

A1.2.2.1. Determine the mass of a clean, empty centrifuge cup (or bowl) to the nearest 0.01 g, and place it in the centrifuge. Position a container at the appropriate spout to catch the effluent from the centrifuging operation. Transfer all of the extract (from Method A, B, D, or E as appropriate) to an appropriate (feed) container suitably equipped with a feed control (valve or clamp, etc.). To ensure quantitative transfer of the extract to the feed container, the receptacle containing the extract should be washed several times with small amounts of clean solvent and the washings added to the feed container. Start the centrifuge, and allow it to reach a constant operational speed (e.g., 9000 r/min for the SMM type and 20,000 + r/min for the Sharples type). Open the feed line, and feed the extract into the centrifuge at a rate of 100 to 150 mL/min. After all the extract has passed through the centrifuge, wash the feed mechanism (with the centrifuge still running) with several increments of clean solvent, allowing each increment to run through the centrifuge until the effluent is essentially colorless.

A1.2.2.2. Allow the centrifuge to stop, and remove the cup (or bowl). Clean the outside with fresh solvent. Allow the residual solvent to evaporate in a funnel or steam hood, and then dry the container in an oven controlled at 110 ± 5°C (230 ± 9°F). Cool the container and redetermine the mass to the nearest 0.01 g immediately. The increase in mass is the mass of mineral matter, W_4 (Section 13), in the extract.

A1.3. *Volumetric Method*:

A1.3.1. *Apparatus*:

A1.3.1.1. Flask.

A1.3.1.2. *Water Bath*—capable of controlling temperature to ±0.1°C (±0.2°F).

A1.3.1.3. *Balance*—conforming to the requirements of M 231, Class G 2.

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A1.3.2. *Procedure*:

A1.3.2.1. Place the extract in a previously tared and calibrated flask. Place the flask in a constant-temperature bath controlled to ±0.1°C (±0.2°F), and allow it to reach the temperature at which the flask was calibrated. When the desired temperature has been reached, fill the flask with solvent at the same temperature. Bring the level of the liquid in the flask up to the neck; insert the stopper, making sure the liquid overflows the capillary, and remove the flask from the bath. Wipe the flask dry; determine the mass to the nearest 0.1 g, and record this mass as the mass of flask plus extract, M_2.

Note A1—Instead of using a controlled temperature bath, the temperature of the extract may be measured and the necessary corrections to the volume of the flask and the density of the asphalt binder and solvent made.

A1.3.2.2. Calculate the volume of asphalt and fines in the extract as follows:

$$V_1 = V_2 - \frac{(M_1 - M_2)}{G_1} \qquad (A1.2)$$

where:

V_1 = volume of asphalt and fines in the extract, mL;

V_2 = volume of the flask, mL;

M_1 = mass of the contents of the flask, g;

M_2 = mass of the asphalt binder and fines in the extract (or mass of the total sample minus the mass of the extracted aggregate), g; and

G_1 = specific gravity of the solvent determined to the nearest 0.001 in accordance with ASTM D 2111.

A1.3.2.3. Calculate the mass of fines in the extract as follows:

$$M_3 = K(M_2 - G_3 V_1) \qquad (A1.3)$$

where:

M_3 = mass of fines in the extract, g;

G_2 = specific gravity of fines as determined in accordance with T 84;

G_3 = specific gravity of asphalt binder as determined in accordance with T 228;

K = $\frac{G_2}{G_2 - G_3}$;

V_1 = as given in Section A1.3.2.2; and

M_2 = as given in Section A1.3.2.2.

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[1] This method is similar to ASTM D 2172-05.

[2] Celite 110, manufactured by Johns-Manville, has been found satisfactory for this purpose; however, all filtering aids should be presieved through a 75-µm (No. 200) sieve when the gradation test on the aggregate is to be performed.

[3] The Sharples Supercentrifuge and the SMM continuous-flow centrifuge have been found suitable for this method.

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Standard Method of Test for

Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens

AASHTO Designation: T 166-11

1. SCOPE

1.1. This method of test covers the determination of bulk specific gravity of specimens of compacted hot mix asphalt (HMA).

1.2. This method should not be used with samples that contain open or interconnecting voids or absorb more than 2.0 percent of water by volume, as determined in Sections 7.2 or 10.2 herein. If the sample contains open or interconnecting voids or absorbs more than 2.0 percent of water by volume, then T 275 or T 331 should be used.

1.3. The bulk specific gravity of the compacted HMA may be used in calculating the unit mass of the mixture.

1.4. The values stated in SI units are to be regarded as the standard.

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

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- T 275, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Paraffin-Coated Specimens
- T 331, Bulk Specific Gravity and Density of Compacted Hot Mix Asphalt (HMA) Using Automatic Vacuum Sealing Method

2.2. *ASTM Standard:*

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D 7227, Standard Practice for Rapid Drying of Compacted Asphalt Specimens Using Vacuum Drying Apparatus

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3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *bulk specific gravity (of solids)*—the ratio of the mass in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature. The form of the expression shall be:

Bulk specific gravity at x/y °C *(1)*

where:

x = temperature of the material; and
y = temperature of the water.

3.1.2. *constant mass*—shall be defined as the mass at which further drying does not alter the mass by more than 0.05 percent when weighed at 2-h intervals when using oven drying, or by more than 0.05 percent when weighed after at least two drying cycles of the vacuum-drying apparatus required in ASTM D 7227.

4. TEST SPECIMENS

4.1. Test specimens may be either laboratory-compacted HMA or sampled from HMA pavements.

4.2. *Size of Specimens*—It is recommended that: (1) the diameter of cylindrically compacted or cored specimens, or the length of the sides of sawed specimens, be at least equal to four times the maximum size of the aggregate; and (2) the thickness of specimens be at least one and one-half times the maximum size of the aggregate.

4.3. Specimens shall be taken from pavements with a core drill, diamond or carborundum saw, or by other suitable means.

4.4. Care shall be taken to avoid distortion, bending, or cracking of specimens during and after the removal from the pavement or mold. Specimens shall be stored in a safe, cool place.

4.5. Specimens shall be free from foreign materials such as seal coat, tack coat, foundation material, soil, paper, or foil.

4.6. If desired, specimens may be separated from other pavement layers by sawing or other suitable means. Care should be exercised to ensure sawing does not damage the specimens.

METHOD A

5. APPARATUS

5.1. *Weighing Device*—The weighing device shall have sufficient capacity, be readable to 0.1 percent of the sample mass or better, and conform to the requirements of M 231. The weighing device shall be equipped with a suitable suspension apparatus and holder to permit weighing the specimen while suspended from the center of the scale pan of the weighing device.

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5.2. *Suspension Apparatus*—The wire suspending the container shall be the smallest practical size to minimize any possible effects of a variable immersed length. The suspension apparatus shall be constructed to enable the container to be immersed to a depth sufficient to cover it and the test sample during weighing. Care should be exercised to ensure no trapped air bubbles exist under the specimen.

5.3. *Water Bath*—For immersing the specimen in water while suspended under the weighing device, equipped with an overflow outlet for maintaining a constant water level.

6. PROCEDURE

6.1. Dry the specimen to a constant mass at a temperature of 52 ± 3°C (125 ± 5°F). Samples saturated with water shall initially be dried overnight and then weighed at 2-h drying intervals. Recently compacted laboratory samples, which have not been exposed to moisture, do not require drying. As an alternative to oven drying to constant mass, drying the sample according to ASTM D 7227 may be used. When using ASTM D 7227 to achieve constant mass, perform the drying procedure at least twice, with a mass determination after each drying cycle.

6.2. Cool the specimen to room temperature at 25 ± 5°C (77 ± 9°F), and record the dry mass as *A* (Note 1). Immerse each specimen in the water bath at 25 ± 1°C (77 ± 1.8°F) for 4 ± 1 min, and record the immersed mass as *C*. Remove the specimen from the water bath, damp-dry the specimen by blotting with a damp towel as quickly as possible (not to exceed 5 s), and determine the surface-dry mass as *B*. Any water that seeps from the specimen during the weighing operation is considered part of the saturated specimen. Each specimen shall be immersed and weighed individually.

Note 1—If desired, the sequence of testing operations may be changed to expedite the test results. For example, first the immersed mass *C* can be taken, then the surface-dry mass *B*, and finally the dry mass *A*.

Note 2—Terry cloth has been found to work well for an absorbent cloth. Damp is considered to be when no water can be wrung from the towel.

7. CALCULATION

7.1. Calculate the bulk specific gravity of the specimen as follows:

$$\text{Bulk Specific Gravity} = \frac{A}{B - C} \qquad (2)$$

where:

A = mass of the specimen in air, g;
B = mass of the surface-dry specimen in air, g; and
C = mass of the specimen in water, g.

7.2. Calculate the percent of water absorbed by the specimen (on a volume basis) as follows:

$$\text{Percent of Water Absorbed by Volume} = \frac{B - A}{B - C} \times 100 \qquad (3)$$

7.3. If the percent of water absorbed by the specimen as calculated in Section 7.2 exceeds 2.0 percent, use either T 275 or T 331 to determine the bulk specific gravity.

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METHOD B

8. APPARATUS

8.1. *Weighing Device*—The weighing device shall have sufficient capacity, be readable to 0.1 percent of the sample mass or better, and conform to the requirements of M 231.

8.2. *Water Bath*—For immersing the specimen in water.

8.3. *Thermometer*—ASTM 17C (17F), having a range of 19 to 27°C (66 to 80°F), graduated in 0.1°C (0.2°F) subdivisions.

8.4. *Volumeter*[1]—Calibrated to 1200 mL, or an appropriate capacity depending on the size of the test sample. The volumeter shall have a tapered lid with a capillary bore.

9. PROCEDURE

9.1. Dry the specimen to a constant mass at a temperature of 52 ± 3°C (125 ± 5°F). Samples saturated with water shall initially be dried overnight and then weighed at 2-h drying intervals. Recently compacted laboratory samples, which have not been exposed to moisture, do not require drying. As an alternative to oven drying to constant mass, drying using ASTM D 7227 may be used. When using ASTM D 7227 to determine the constant mass, follow the drying procedure at least twice, with a mass determination after each drying procedure.

9.2. Cool the specimen to room temperature at 25 ± 5°C (77 ± 9°F), and record the dry mass as *A* (Note 1). Immerse the specimen in the water bath at 25 ± 1°C (77 ± 1.8°F), and let it saturate for at least 10 min. At the end of the 10-min period, fill a calibrated volumeter with distilled water at 25 ± 1°C (77 ± 1.8°F), and weigh the volumeter. Designate this mass as *D*. Remove the saturated specimen from the water bath and damp-dry the specimen by blotting with a damp towel (Note 2) as quickly as possible (not to exceed 5 s). Weigh the specimen, and record the surface-dry mass as *B*. Any water that seeps from the specimen during the weighing operation is considered part of the saturated specimen.

9.3. Place the specimen into the volumeter, and let it stand for at least 60 s. Bring the temperature of the water to 25 ± 1°C (77 ± 1.8°F), and cover the volumeter, making certain that some water escapes through the capillary bore of the tapered lid. Wipe the outside of the volumeter dry with a dry, absorbent cloth, and weigh the volumeter and its contents (Note 3). Record this weight as *E*.

Note 3—If desired, the sequence of testing operations can be changed to expedite the test results. For example, first the mass of the saturated, damp-dry specimen *B* can be taken. Then the volumeter containing the saturated specimen and water *E* can be weighed. The dry mass of the specimen *A* can be determined last.

Note 4—Method B is not acceptable for specimens that have more than 6 percent air voids.

10. CALCULATIONS

10.1. Calculate the bulk specific gravity of the specimen as follows:

$$\text{Bulk Specific Gravity} = \frac{A}{B + D - E} \qquad (4)$$

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where:

A = mass of the dry specimen, g;
B = mass of the surface-dry specimen, g;
D = mass of the volumeter filled with water at 25 ± 1°C (77 ± 1.8°F), g; and
E = mass of the volumeter filled with the specimen and water at 25 ± 1°C (77 ± 1.8°F), g.

10.2. Calculate the percent of water absorbed by the specimen (on a volume basis) as follows:

$$\text{Percent of Water Absorbed by Volume} = \frac{B - A}{B + D - E} \times 100 \qquad (5)$$

10.3. If the percent of water absorbed by the specimen as calculated in Section 10.2 exceeds 2.0 percent, use either T 275 or T 331 to determine the bulk specific gravity.

METHOD C (RAPID TEST)

11. PROCEDURE

11.1. This procedure can be used for testing specimens which are not required to be saved and which contain a substantial amount of moisture. Specimens obtained by coring or sawing can be tested the same day by this method.

11.2. The testing procedure shall be the same as given in Sections 6 or 9 except for the sequence of operations. The dry mass A of the specimen is determined last as follows.

11.3. Place the specimen in a large, flat-bottom drying pan of known mass. Place the pan and specimen in an oven at 110 ± 5°C (230 ± 9°F). Leave the specimen in the oven until it can be easily separated to the point where the particles of the fine aggregate-asphalt portion are not larger than 6.3 mm ($^1/_4$ in.). Place the separated specimen in an oven at 110 ± 5°C (230 ± 9°F), and dry to a constant mass.

11.4. Cool the pan and specimen to room temperature at 25 ± 5°C (77 ± 9°F). Determine the mass of the pan and specimen; subtract the mass of the pan, and record as the dry mass A.

12. CALCULATIONS

12.1. Calculate the bulk specific gravity as given in Sections 7.1 or 10.1.

13. REPORT

13.1. The report shall include the following:

13.1.1. The method used (A, B, or C).

13.1.2. Bulk Specific Gravity reported to the nearest thousandth.

13.1.3. Absorption reported to the nearest hundredth.

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14. PRECISION

Table 1—Precision Estimates for AASHTO T 166

Condition of Test	Standard Deviation (1s)[a]	Acceptable Range of Two Results (d2s)[a]
Single-operator precision	0.002	0.006
Multilaboratory precision	0.006	0.017

[a] These values represent the 1s and 2ds limits described in ASTM C 670.

Note: Based on interlaboratory study described in NCHRP Research Report 9-26 Phase 2 involving 150-mm diameter specimens, 20 laboratories, three materials (9.5-mm, 12.5-mm, and 19.0-mm mixtures), and two replicates.

[1] Suitable aluminum volumeters of different sizes are available from Pine Instrument Co., 101 Industrial Drive, Grove City, PA 16127; and Rainhart Co., 604 Williams St., Austin, TX 78765.

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Standard Method of Test for

Sampling Bituminous Paving Mixtures

AASHTO Designation: T 168-03 (2011)
ASTM Designation: D 979-01 (2006)$^{\epsilon 1}$

AASHTO T 168-03 (2011) is identical to ASTM D 979-01 (2006)$^{\epsilon 1}$ except for the following provisions:

1. All references to the ASTM standards listed in the following table, shall be replaced with the corresponding AASHTO standard:

Referenced Standard	
ASTM	AASHTO
C 702	T 248

2. Insert an additional section between Sections 4.1.1 and 4.1.2 containing the following:

   Care shall be taken in sampling to avoid segregation of coarse aggregate and asphalt mortar. Care shall be taken also to prevent contamination by dust or other foreign matter.

3. Insert new Sections 5.2.3.3, 5.2.3.4, and 5.2.3.5 after Section 5.2.3.2 as follows:

   5.2.3.3 If the mixture is in a windrow (cold mix), random samples of the windrow at intervals of not more than 150 m (500 ft) shall be secured and tested separately. Samples of the windrow shall be secured by flattening it at one point into a layer of approximately 0.3 m (1 ft) thick and coring this layer at three or more random points to obtain the required sample size as shown in Table 1.

   5.2.3.4 If the mix has been bladed into a relatively uniform layer, samples shall be secured at intervals of not more than 150 m (500 ft).

   5.2.3.5 Samples from a stockpile shall be obtained by combining equal quantities of the mixture taken from holes dug into points near the top, middle, and bottom of the stockpile. Reduction of the sample to the required size shall be as described in Section 5.3.2.

4. Insert an additional section between Sections 6.2.3 and 6.2.4 containing the following:

   Lot number.

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Standard Method of Test for

Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)

AASHTO Designation: T 209-11

1. SCOPE

1.1. This test method covers the determination of the theoretical maximum specific gravity and density of uncompacted hot mix asphalt (HMA) at 25°C (77°F).

Note 1—The precision of the method is best when the procedure is performed on samples that contain aggregates that are completely coated. In order to assure complete coating, it is desirable to perform the method on samples that are close to the optimum asphalt binder content.

1.2. The values stated in SI units are to be regarded as the standard.

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

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- PP 57, Establishing Requirements for and Performing Equipment Calibrations, Standardizations, and Checks
- R 47, Reducing Samples of Hot Mix Asphalt (HMA) to Testing Size
- T 168, Sampling Bituminous Paving Mixtures

2.2. *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D 4311/D 4311M, Standard Practice for Determining Asphalt Volume Correction to a Base Temperature

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *density, as determined by this test method*—the mass of a cubic meter of the material at 25°C (77°F) in SI units, or the mass of a cubic foot of the material at 25°C (77°F) in inch–pound units.

3.1.2. *residual pressure, as employed by this test method*—the pressure in a vacuum vessel when vacuum is applied.

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3.1.3. *specific gravity, as determined by this test method*—the ratio of a given mass of material at 25°C (77°F) to the mass of an equal volume of water at the same temperature.

4. SUMMARY OF TEST METHOD

4.1. A weighed sample of oven-dry HMA in the loose condition is placed in a tared vacuum container Sufficient water at a temperature of 25 ± 0.5°C (77 ± 0.9°F) is added to completely submerge the sample. Vacuum is applied for 15 ± 2 min to gradually reduce the residual pressure in the vacuum container to 3.7 ± 0.3 kPa (27.5 ± 2.5 mmHg). At the end of the vacuum period, the vacuum is gradually released. The volume of the HMA sample is obtained either by immersing the vacuum container with the sample into a water bath and determining the mass (Section 13.1) or by filling the vacuum container level full of water and determining the mass in air (Section 13.2). At the time of weighing, the temperature is measured as well as the mass. From the mass and volume measurements, the specific gravity or density at 25°C (77°F) is calculated. If the temperature employed is different than 25°C (77°F), an appropriate correction is applied.

5. SIGNIFICANCE AND USE

5.1. The theoretical maximum specific gravities and densities of HMA are intrinsic properties whose values are influenced by the composition of the mixtures in terms of types and amounts of aggregates and asphalt materials.

5.1.1. These properties are used to calculate percent air voids in compacted HMA.

5.1.2. These properties provide target values for the compaction of HMA.

5.1.3. These properties are essential when calculating the amount of asphalt binder absorbed by the internal porosity of the individual aggregate particles in HMA.

6. APPARATUS

6.1. Follow the procedures for performing equipment calibrations, standardizations, and checks found in PP 57.

6.2. *Vacuum Container*:

6.2.1. The vacuum containers described must be capable of withstanding the full vacuum applied, and each must be equipped with the fittings and other accessories required by the test procedure being employed. The opening in the container leading to the vacuum pump shall be covered by a piece of 0.075-mm (No. 200) wire mesh to minimize the loss of fine material.

6.2.2. The capacity of the vacuum container should be between 2000 and 10 000 mL and depends on the minimum sample size requirements given in Section 7.2. Avoid using a small sample in a large container.

6.2.3. *Vacuum Bowl*—Either a metal or plastic bowl with a diameter of approximately 180 to 260 mm (7 to 10 in.) and a bowl height of at least 160 mm (6.3 in.) equipped with a transparent cover fitted with a rubber gasket and a connection for the vacuum line.

6.2.4. *Vacuum Flask for Mass Determination in Air Only (Section 13.2)*—A thick-walled volumetric glass flask and a rubber stopper with a connection for the vacuum line.

6.2.5. *Pycnometer for Mass Determination in Air Only*—A glass, metal, or plastic pycnometer.

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6.3. *Balance*—A balance conforming to the requirements of AASHTO M 231, Class G 2. The balance shall be standardized at least every 12 months.

6.3.1. For the mass determination-in-water method (see Section 13.1), the balance shall be equipped with a suitable apparatus and holder to permit determining the mass of the sample while suspended below the balance. The wire suspending the holder shall be the smallest practical size to minimize any possible effects of a variable immersed length.

6.4. *Vacuum Pump or Water Aspirator*—Capable of evacuating air from the vacuum container to a residual pressure of 4.0 kPa (30 mmHg).

6.4.1. When a vacuum pump is used, a suitable trap of one or more filter flasks, or equivalent, shall be installed between the vacuum vessel and vacuum source to reduce the amount of water vapor entering the vacuum pump.

6.5. *Vacuum Measurement Device*—Residual pressure manometer[1] or vacuum gauge to be connected directly to the vacuum vessel and capable of measuring residual pressure down to 4.0 kPa (30 mmHg) or less (preferably to zero). The gauge shall be standardized at least annually and be accurate to 0.1 kPa (1 mmHg.). It shall be connected at the end of the vacuum line using an appropriate tube and either a "T" connector on the top of the vessel or a separate opening (from the vacuum line) in the top of the vessel to attach the hose. To avoid damage, the manometer shall not be situated on top of the vessel.

Note 2—A residual pressure of 4.0 kPa (30 mmHg) absolute pressure is approximately equivalent to a 97 kPa (730 mmHg) reading on a vacuum gauge at sea level.

Note 3—Residual pressure in the vacuum container, measured in millimeters of mercury, is the difference in the height of mercury in the Torricellian vacuum leg of the manometer and the height of mercury in the other leg of the manometer that is attached to the vacuum container.

Note 4—An example of a correct arrangement of the testing equipment is shown in Figure 1. In the figure, the purpose of the train of small filter flasks is to trap water vapor from the vacuum container that otherwise would enter the oil in the vacuum pump and decrease the pump's ability to provide adequate vacuum. Insertion of a valve to isolate the line to each vacuum chamber can reduce wear on the bleeder valve atop each chamber and assist in tracing sealing leaks.

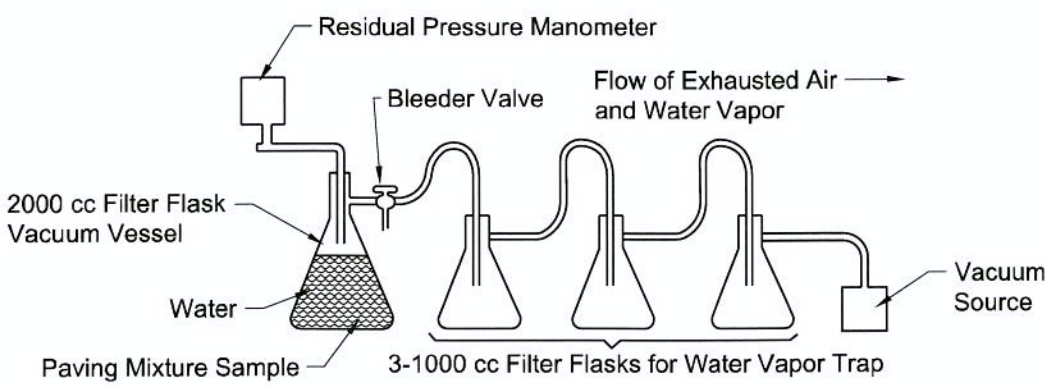

Figure 1—Example of Correct Arrangement of Testing Apparatus

6.6. *Bleeder Valve*—attached to the vacuum train to facilitate adjustment of the vacuum being applied to the vacuum container.

6.7. *Thermometric Device (Mass Determination in Air)*—A liquid-in-glass thermometer or other thermometric device, accurate to 0.5°C (1°F), of suitable range with subdivisions of 0.5°C (1°F). The thermometric device shall be standardized at the test temperature at least every 12 months.

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6.8. *Water Bath*:

6.8.1. For vacuum bowls, a water bath capable of maintaining a constant temperature between 20 and 30°C (68 and 86°F) is required. (See Appendix X for a method for correcting the theoretical maximum specific gravity to 25°C (77°F) when measurements are made at temperatures other than 25°C (77°F)).

6.8.2. *Thermometric Device (Mass Determination in Water)*—A liquid-in-glass thermometer or other thermometric device, accurate to 0.5°C (1°F) shall be used to measure the temperature of the water bath. The thermometric device shall be standardized at least every 12 months.

6.8.3. When using the mass determination-in-water technique (Section 13.1), the water bath must be suitable for immersion of the suspended container with its deaerated sample.

6.9. *Drying Oven*—A thermostatically controlled drying oven capable of maintaining a temperature of 135 ± 5°C (275 ± 9°F) or 105 ± 5°C (221 ± 9°F).

6.9.1. *Thermometric Device*—A liquid-in-glass thermometer or other thermometric device accurate to 3°C (5°F) shall be used to measure the temperature of the oven. The thermometric device shall be standardized at least every 12 months.

6.10. *Protective Gloves*—used when handling glass equipment under vacuum.

7. SAMPLING

7.1. Field samples shall be obtained in accordance with T 168. Sampling is not required for laboratory-prepared materials.

7.2. The size of the sample shall conform to the following requirements. Samples larger than the capacity of the container may be tested a portion at a time.

Table 1—Minimum Sample Sizes

Nominal Maximum Aggregate Size, mm	Minimum Sample Size, g
37.5 or greater	4000
19 to 25	2500
12.5 or smaller	1500

8. STANDARDIZATION OF FLASKS, BOWLS, AND PYCNOMETERS

8.1. For the mass determination-in-water method (Section 13.1), standardize the vacuum bowls for temperature correction by determining the mass of each container when immersed in water over the range of water bath temperatures likely to be encountered in service (Figure 2).

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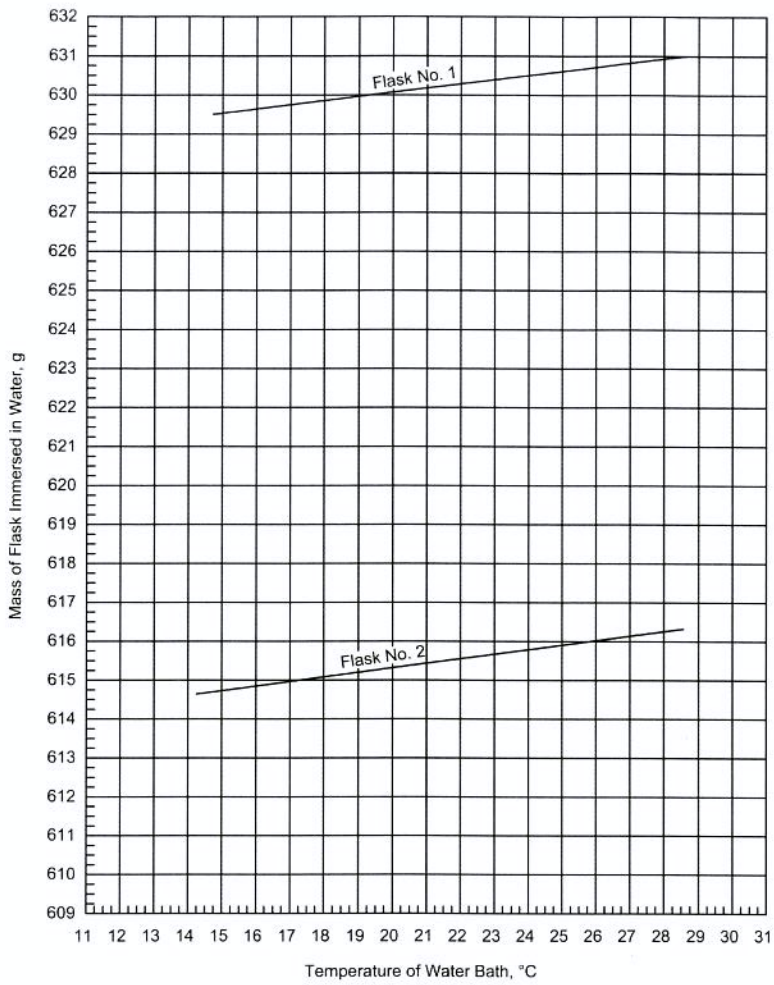

Figure 2—Example Standardization Curve for Volumetric Flask

8.2. For the mass determination-in-air method (Section 13.2), standardize the volumetric flasks or pycnometers for temperature correction by determining the mass of the container when filled with water over the range of water bath temperatures likely to be encountered in service (Figure 3). When standardized at 25 ± 0.5°C (77 ± 0.9°F), designate this mass as *D*. Accurate filling may be ensured by the use of a glass cover plate.

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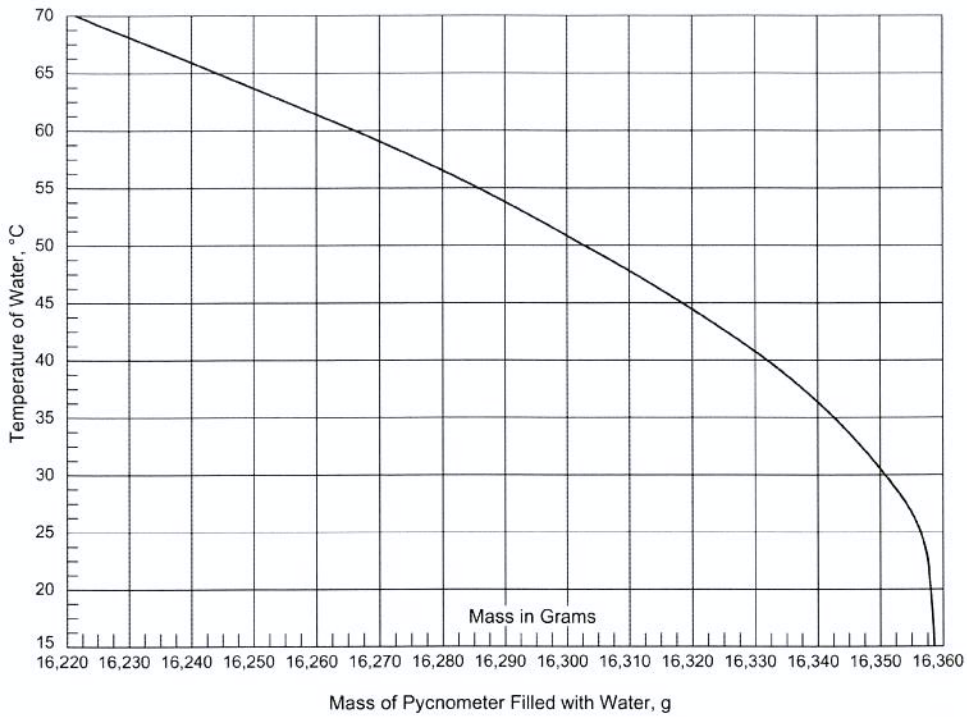

Figure 3—Example Standardization Curve for Pycnometer

8.3. Standardize the large-size plastic pycnometer by accurately determining the mass of water required to fill it over a range of temperature from about 20 to 65°C (70 to 150°F), and construct a standardization curve of mass versus temperature as shown in Figure 3. Care should be taken to follow exactly the same procedure in standardization as in conducting a test.

8.3.1. The following filling procedure may be used for the model with a latched lid and vented stopper. The domed lid is latched in place and the pycnometer nearly filled with water. Leave about 50 mm (2 in.) empty. The release of air bubbles may be facilitated by applying vacuum and by dropping first one side then the other of the pycnometer about 10 mm ($^1/_2$ in.) above a hard, flat surface. This vacuum application and bubble release procedure should take about 10 min so that the temperature equilibrium between the shell and the water approximates that attained when performing a test. The final amount of water is then gently poured in until the level is about halfway up the neck. Any air bubbles caught against the dome that cannot be released by jarring or by swirling the water may be "pricked" or pushed to the surface with a bent wire or other suitable device. Insert the vented stopper using only enough force to just seat the stopper and immediately wipe the excess water off the top.

8.3.2. For the models with a quick-disconnect vacuum line and unlatched lid, the filling procedure is as follows. With the inlet valve closed, apply a vacuum of about 30 kPa (225 mmHg). Open the inlet valve slowly, letting water in until the level reaches 25 mm (1 in.) below the top of the dome and close the valve. Continue applying vacuum and release the bubbles by jarring and rapping the vessel with a rubber mallet. Slowly open the inlet valve and allow more water in until the water overflows into the aspirator (vacuum) line and then close the valve. This vacuum application and bubble release procedure should take about 10 min, so that the temperature equilibrium between the shell and the water approximates that attained when performing a test. Disconnect the vacuum line by pulling it out at the quick-disconnect joint below the gauge.

8.3.3. Wipe the outside of the pycnometer dry, determine the mass of the full pycnometer, and measure the water temperature.

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Note 5—The shape of the standardization curve is a function of two opposing factors that can be rationally defined. As the temperature is increased, the container itself expands (adding mass—"Pycnometer" line in Figure 4) and the density of the contained water decreases (resulting in loss of mass—"Water" line in Figure 4). These relationships are shown in Figure 4 for a typical large-size pycnometer. The "Water" curve may be constructed by multiplying the volume at 25°C (77°F) by the difference between the density of water at 25°C (77°F), which is 0.9970, and the density of water at the standardization temperature (see Equation 1).

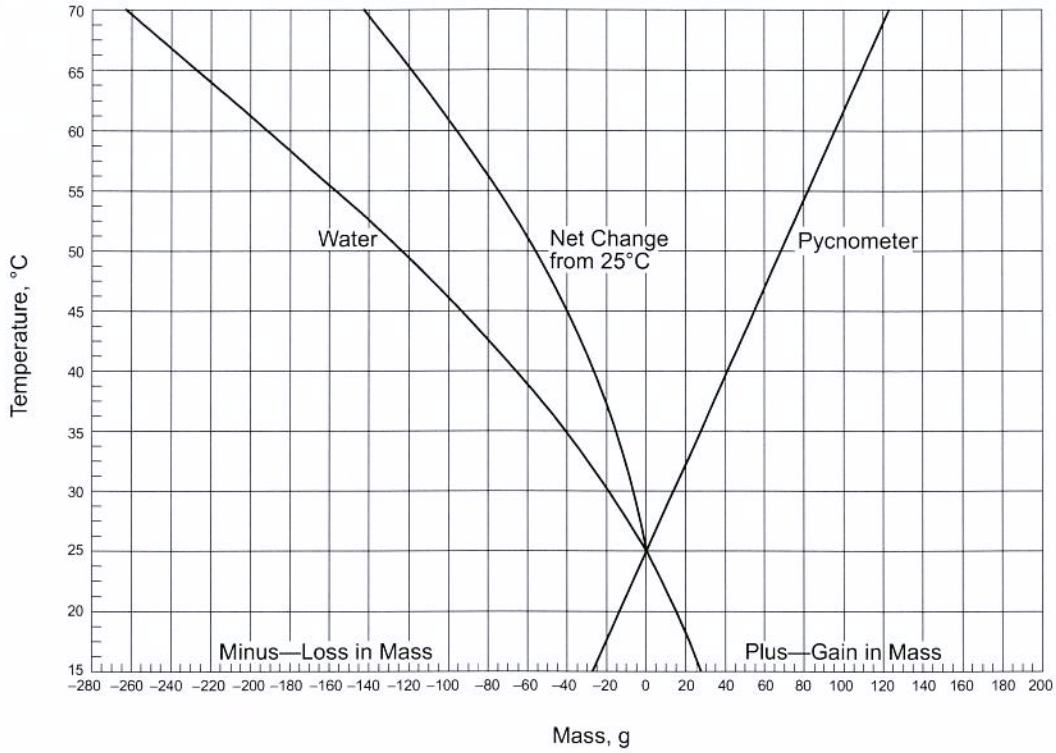

Figure 4—Effect of Change in Density of Water and Volume of Pycnometer with Change in Temperature

$$\text{Difference Due to Water Expansion} = V_{25}(0.9970 - dw)$$

$$\text{Since } V_{25} = W_{25} / 0.9970$$

$$V_{25}(0.9970 - dw) \text{ reduces to } W_{25}\left(1 - \frac{dw}{0.9970}\right) \qquad (1)$$

where:

V_{25} = volume of water to fill a container at 25°C (77°F), cm^3;

W_{25} = mass of water to fill a container at 25°C (77°F), g; and

dw = density of water at the standardization temperature, Mg/m^3.

The rate of change in capacity of the container due to thermal expansion of the pycnometer itself is essentially constant over the temperature range from 20 to 65°C (70 to 150°F). Thus, the "Pycnometer" line in Figure 4 can be drawn through the 0 at 25°C (77°F) point, knowing only the slope of the straight-line relationship. The slope can be established by averaging at least five standardization mass determinations at some elevated temperature, adding the loss due to water expansion, and subtracting the mass at 25°C (77°F), W_{25}, to give the gain in capacity due to

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expansion of the container. The difference in mass divided by the difference in temperature is the slope of the "Pycnometer" line. For a polycarbonate pycnometer of about 13 500-mL capacity, the slope thus established was 2.75 g/°C (1.53 g/°F). This value is believed to be typical and reasonably constant.

The bending of the standardization curve (Figure 3) due to these offsetting thermal factors thus minimizes experimental error due to temperature effects in the normal working range, 25°C (77°F), for both the volumetric flask and the pycnometer containers. Defining the standardization curve makes it possible to correct for temperature, rather than "bringing the container and sample to temperature," thereby eliminating the cost of a water bath and making it feasible to improve accuracy by testing larger samples and to materially reduce the testing time.

8.4. While standardization of the flask or either pycnometer need to be performed only once, the standardization should be checked occasionally, particularly at 25°C (77°F). The equipment must be kept clean and free from any accumulation that would change the mass if the volume standardization is to remain constant. Care should be taken to use only neutral solvents, especially with plastic containers; glass vessels should not be subjected to high vacuum if they are scratched or damaged.

9. SAMPLE PREPARATION

9.1. Separate the particles of the HMA sample by hand, taking care to avoid fracturing the aggregate, so that the particles of the fine aggregate portion are not larger than 6.3 mm ($^1/_4$ in.). If an HMA sample is not sufficiently soft to be separated manually, place it in a pan and warm it in an oven until it can be separated as described.

9.2. Samples prepared in a laboratory shall be conditioned and dried in an oven at 135 ± 5°C (275 ± 9°F) for a minimum of 2 h or as appropriate to match the mix design procedure being used. Longer drying time may be necessary for the sample to achieve a constant mass (mass repeats within 0.1 percent). HMA which has not been prepared in a laboratory with oven-dried aggregates shall be dried to a constant mass at a temperature of 105 ± 5°C (221 ± 9°F). This drying and conditioning operation shall be combined with any warming described in Section 9.1.

Note 6—The minimum 2 h time in the oven is specified as the short-term conditioning time for laboratory-prepared specimens. The short-term conditioning at the specified temperature is especially important when absorptive aggregates are used. This short-term conditioning will ensure the computation of realistic values for the amount of asphalt absorbed by the aggregate and void properties of the mix. Plant-produced HMA should not be short-term conditioned since absorption takes place during production.

9.3. Cool the sample to room temperature, and place it in a tared and standardized flask, bowl, or pycnometer. The sample is to be placed directly into a vacuum container. A container within a container is not to be used. Determine the mass and designate the net mass of the sample as A. Add sufficient water at a temperature of approximately 25°C (77°F) to cover the sample completely.

Note 7—The release of entrapped air may be facilitated by the addition of a suitable wetting agent such as Aerosol OT in concentration of 0.001 percent or 0.2 g in 20 L of water. This solution is then diluted by about 20:1 to make a wetting agent of which 5 to 10 mL may be added to the apparatus.

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TEST METHOD A—MECHANICAL AGITATION

10. APPARATUS

10.1. In addition to the apparatus listed in Section 6, the following apparatus is required for Method A:

10.1.1. *Mechanical Shaker*—Shaker for removing air from asphalt mix.

11. PROCEDURE

11.1. Remove air trapped in the sample by applying gradually increased vacuum until the residual pressure manometer reads 3.7 ± 0.3 kPa (27.5 ± 2.5 mmHg). Maintain this residual pressure for 15 ± 2 min. Agitate the container and contents using the mechanical device during the vacuum period. Glass vessels should be shaken on a resilient surface such as a rubber or plastic mat, and not on a hard surface, so as to avoid excessive impact while under vacuum.

11.2. At the end of the vacuum period, release the vacuum by increasing the pressure at a rate not to exceed 8 kPa (60 mmHg) per second and proceed with one of the mass determination methods in Section 13.

TEST METHOD B—MANUAL AGITATION

12. PROCEDURE

12.1. Remove air trapped in the sample by applying gradually increased vacuum until the residual pressure manometer reads 3.7 ± 0.3 kPa (27.5 ± 2.5 mmHg). Maintain this residual pressure for 15 ± 2 min. Agitate the container and contents during the vacuum period by vigorously shaking at intervals of about 2 min. Glass vessels should be shaken on a resilient surface such as a rubber or plastic mat, and not on a hard surface, so as to avoid excessive impact while under vacuum.

12.2. At the end of the vacuum period, release the vacuum by increasing the pressure at a rate not to exceed 8 kPa (60 mmHg) per second and proceed with one of the mass determination methods in Section 13.

13. MASS DETERMINATION

13.1. *Mass Determination in Water*—Suspend the container and contents in the water bath and determine the mass after a 10 ± 1 min immersion. Measure the water bath temperature, and if different from 25 ± 1°C (77 ± 2°F), correct the mass to 25°C (77°F) using the standardization temperature adjustment developed in Section 8.1. Designate the mass of the sample in water at 25°C (77°F) as *C*.

Note 8—Instead of using a chart like Figure 2 to establish the mass correction for the temperature of the vacuum vessel submerged by itself in the water bath, this correction can be easily established by rapidly and completely emptying the vacuum container immediately following the final mass determination, and then without delay, determining the mass of the vessel by itself when totally submerged in the water bath.

13.2. *Mass Determination in Air*—Fill the flask or any of the pycnometers with water, and adjust the contents to a temperature of 25 ± 1°C (77 ± 2°F). Determine the mass of the container and contents, completely filled, in accordance with Section 8.2 within 10 ± 1 min after completing Section 11.2 or 12.2. Designate this mass as *E*.

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Note 9—See Appendix X1 for correcting the theoretical maximum specific gravity when measurements are made at temperatures other than 25°C (77°F).

14. CALCULATION

14.1. Calculate the theoretical maximum specific gravity of the sample at 25°C (77°F) as follows:

14.1.1. *Mass Determination in Water*:

$$\text{Theoretical Maximum Specific Gravity} = \frac{A}{A - C} \qquad (2)$$

where:

A = mass of the oven-dry sample in air, g; and

C = mass of the sample in water at 25°C (77°F), g.

14.1.2. *Mass Determination in Air*:

$$\text{Theoretical Maximum Specific Gravity} = \frac{A}{A + D - E} \qquad (3)$$

where:

A = mass of the oven-dry sample in air, g;

D = mass of the container filled with water at 25°C (77°F), g; and

E = mass of the container filled with the sample and water at 25°C (77°F), g.

14.1.3. *Large-Size Plastic Pycnometer Determinations*:

14.1.3.1. If the test temperature is between 22.2 and 26.7°C (72 and 80°F), Equation 3 may be used to calculate specific gravity within a minor amount of error due to thermal effects (0.001 points or less).

14.1.3.2. If the test temperature differs significantly from 25°C (77°F), correct for thermal effects as follows:

$$\text{Specific Gravity} = \frac{A}{(A+F)-(G+H)} \times \frac{dw}{0.9970} \qquad (4)$$

where:

A = mass of the oven-dry sample in air, g;

F = mass of the pycnometer filled with water at the test temperature (Figure 3), g;

G = mass of the pycnometer filled with water and the sample at the test temperature, g;

H = correction for thermal expansion of asphalt (Figure 5), g;

dw = density of water at the test temperature, Curve D in Figure 6, Mg/m^3; and

0.9970 = density of water at 25°C (77°F), Mg/m^3.

The ratio (dw/0.9970) is Curve R in Figure 6.

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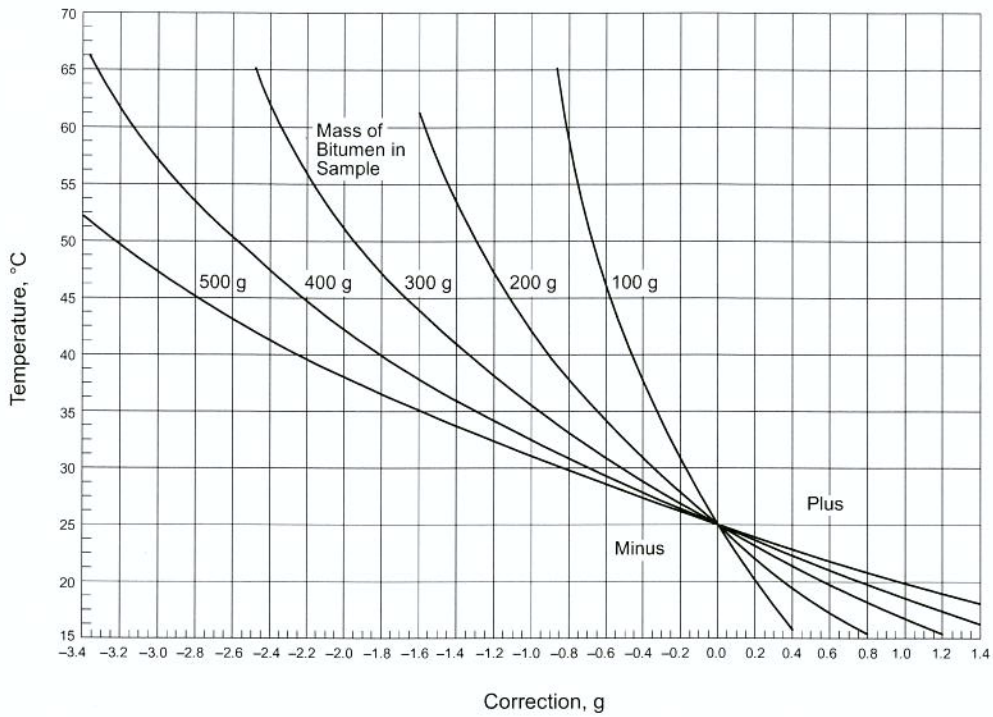

Figure 5—Correction Curves for Expansion of Asphalt, *H*, in Equation 4

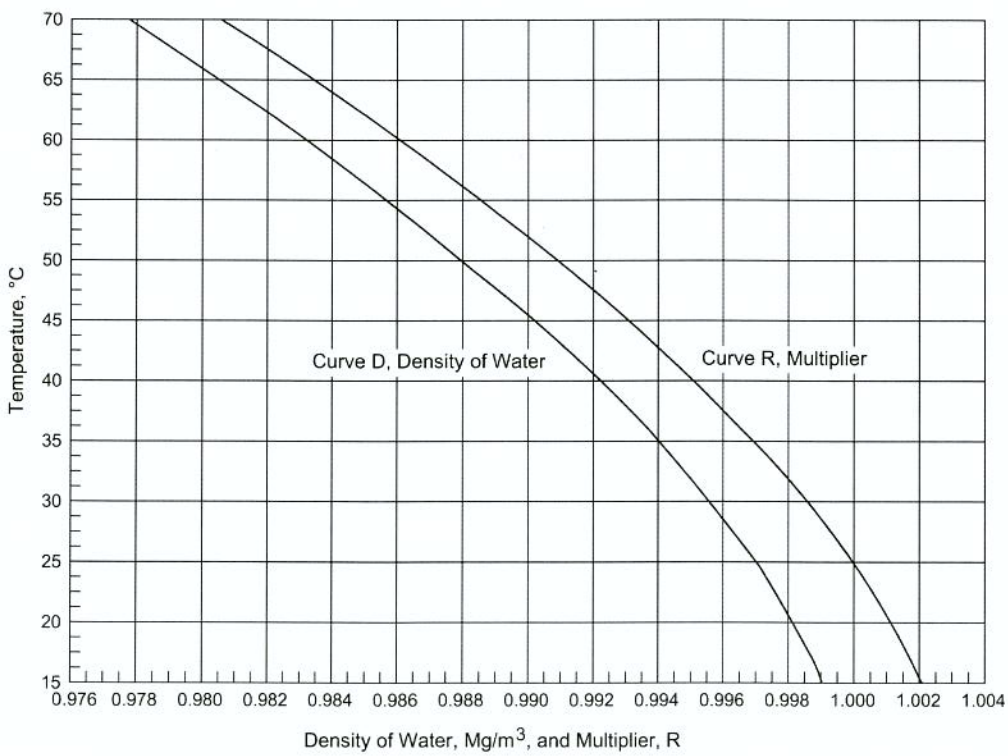

Figure 6—Curves D and R for Equation 4

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Note 10—This general procedure for correcting for thermal effects should also be applicable to corresponding measurements made with other suitable containers.

Note 11—When samples are tested a portion at a time, differences between the maximum specific gravities for each portion should be within the precision statements listed in Section 17. If the values are within the precision statements, the specific gravities for each portion shall be averaged. If the values are outside the precision statements, the test shall be performed again.

14.2. *Theoretical maximum density at 25°C (77°F)*:

14.2.1. Calculate the corresponding theoretical maximum density at 25°C (77°F) as follows:

Theoretical maximum density at 25°C (77°F) = theoretical maximum specific gravity × 997.1 kg/m^3 in SI units, or

Theoretical maximum density at 25°C (77°F) = theoretical maximum specific gravity × 62.245 lb/ft^3 in inch–pound units.

where:

The density of water at 25°C (77°F) = 997.1 kg/m^3 in SI units or 62.245 lb/ft^3 in inch–pound units.

15. SUPPLEMENTAL PROCEDURE FOR MIXTURES CONTAINING POROUS AGGREGATE

Note 12—Experiments indicate that this supplemental procedure has an insignificant effect on the test results if the HMA contains individual aggregate with a water absorption below 1.5 percent.

15.1. If the pores of the aggregates are not thoroughly sealed by an asphalt film, they may become saturated with water during the application of vacuum. To determine if this condition has occurred, proceed as follows after completing Section 13.1 or 13.2. Drain the water from the sample. To prevent the loss of fine particles, decant the water through a towel held over the top of the container. Break several large pieces of aggregate and examine the broken surfaces for wetness.

15.2. If the aggregate has absorbed water, spread the sample before an electric fan to remove the surface moisture. Determine the mass at 15 min intervals, and when the loss in mass is less than 0.05 percent for this interval, the sample may be considered to be surface dry. This procedure requires about 2 h and shall be accompanied by intermittent stirring of the sample. Break conglomerations of HMA by hand. Take care to prevent loss of the HMA particles.

15.3. To calculate the specific gravity of the sample, substitute the final surface-dry mass determined in Section 15.2 for A in the denominator of Equation 2 or 3 as appropriate.

16. REPORT

16.1. *Report the following information*:

16.1.1. Specific gravity and density of the HMA to the nearest 0.001 for specific gravity or nearest 1 kg/m^3 (0.1 lb/ft^3) for density as follows: sp gr 25/25°C (77/77°F) or density at 25°C (77°F),

16.1.2. Type of HMA,

16.1.3. Size of the sample,

16.1.4. Number of samples,

16.1.5. Type of container, and

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16.1.6. Type of procedure.

17. PRECISION

17.1. Criteria for judging the acceptability of specific gravity test results obtained by this test method are given in the following table:

Table 2—Precision Estimates

Test and Type Index	Standard Deviation (1s)	Acceptable Range of Two Results (d2s)
Test results obtained without use of Section 15		
Method A [a]		
Single-operator precision	0.0051	0.014
Multilaboratory precision	0.0084	0.024
Method B [b]		
Single-operator precision	0.0064	0.018
Multilaboratory precision	0.0103	0.029

[a] Basis of estimate: 1 replicate, 1 material, 344 laboratories.
[b] Basis of estimate: 1 replicate, 1 material, 134 laboratories.

17.2. The figures given in Column 2 are the standard deviations that have been found to be appropriate for the conditions of the test described in Column 1. The figures given in Column 3 are the limits that should not be exceeded by the difference between the results of two properly conducted tests. Multilaboratory precision has not been verified for 4500-mL or larger pycnometers.

17.3. The values in Column 3 are the acceptable range for two tests. When more than two results are being evaluated, the range given in Column 3 must be increased. Multiply the standard deviation(s) in Column 2 by the multiplier given in Table 1 of ASTM C 670 for the number of actual tests.

Example for three tests: $0.004 \times 3.3 = 0.013$.

Additional guidance and background is given in ASTM C 670.

APPENDIX

(Nonmandatory Information)

X1. THEORETICAL MAXIMUM SPECIFIC GRAVITY FOR LOOSE HMA

X1.1. *Scope*:

X1.1.1. This appendix has two objectives:

X1.1.1.1. To indicate a method for correcting the theoretical maximum specific gravity to 25°C (77°F) when measurements are made at temperatures other than 25°C (77°F).

X1.1.1.2. To indicate the range of temperature in °C above or below 25°C (77°F) within which no temperature correction is required, because the measured theoretical maximum specific gravity values are shown to be 0.0004 or less away from the value determined at 25°C (77°F).

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X1.2. *Indicated Values*:

X1.2.1. The following example values are indicated for the theoretical maximum specific gravity of a loose HMA sample:

X1.2.1.1. Mass of the loose HMA sample = 1251.3 g.

X1.2.1.2. Volume of the loose HMA sample at 25°C (77°F) = 492.77 mL.

X1.2.1.3. Asphalt binder content = 5.0 percent of total mix.

X1.2.1.4. Specific gravity of the asphalt at 25°C (77°F) = 1.029.

X1.2.1.5. Combined bulk specific gravity of the aggregate = 2.714.

X1.2.1.6. Cubical coefficient of expansion of the asphalt binder at 20°C (68°F) = 6.2×10^{-4} mL/mL/°C (ASTM D 4311/D 4311M).

X1.2.1.7. Cubical coefficient of expansion of the aggregate at 20°C (68°F) = 2.2×10^{-5} mL/mL/°C.[2]

X1.3. *Basis of Calculation for One Gram of Loose HMA at 20°C (68°F)*:

X1.3.1. Mass of the asphalt binder = 0.05 g.

X1.3.2. Volume of the asphalt binder = 0.05/1.029 = 0.0486 mL.

X1.3.3. Mass of the aggregate = 0.95 g.

X1.3.4. Volume of the aggregate = 0.95/ 2.714 = 0.3500 mL.

X1.3.5. Volume of the asphalt binder plus aggregate in one gram of loose HMA at 20°C (68°F) = 0.0486 + 0.3500 = 0.3986 mL.

X1.4. *Basis of Calculation for Volume Change of One Gram of Loose HMA for1°C (2°F) from 20°C (68°F)*:

X1.4.1. Volume change for the asphalt binder = $6.2 \times 10^{-}4 \times 0.0486 = 0.3013 \times 10^{-4}$ mL = 3.0130×10^{-5} mL.

X1.4.2. Volume change for the aggregate = $2.2 \times 10^{-5} \times 0.3500 = 0.77 \times 10^{-5}$ mL.

X1.4.3. Volume change for of one gram of loose HMA for 1°C (2°F) change in temperature from 20°C (68°F) = $3.0130 \times 10^{-5} + 0.7700 \times 10^{-5} = 3.7830 \times 10^{-5}$ mL.

X1.5. *Volume Correction*:

X1.5.1. For a difference in water temperature of 1°C (2°F) above or below 20°C (68°F), a correction to the volume of water displaced by one gram of loose HMA can be made by the following equation:

$$\text{Correction} = \Delta T \times K_T \times V_T \text{ mL} \qquad (X1.1)$$

where:

ΔT = 1°C (2°F),

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K_T = volume change of 1 g of loose HMA for a 1°C (2°F) change in temperature above or below 20°C (68°F) = 3.7830×10^{-5} mL, and

V_T = volume of water for a corresponding 1251.3-g mass of loose HMA at a test temperature of 20°C (68°F) = 492.77 mL.

Substituting these values into the equation gives the following:

Correction = $1 \times 3.7830 \times 10^{-5} \times 492.77 = 0.01864$ mL/g at 20°C (68°F).

X1.6. Table X1.1 illustrates an example of the influence of temperature corrections. For a measured volume and a given mass of HMA tested at specific temperatures, this table relates these influences to the specific gravity of the HMA.

Table X1.1—Influence of Temperature Corrections to a Measured Volume at 20°C of a Given Mass of Loose Paving Mixture, to Provide the Required Theoretical Maximum Specific Gravity at 25°C

Temperature, °C	Volume of HMA at 20°C (68°F), mL	Volume Correction for Temp Change	Corrected Volume of HMA at 20°C (68°F), mL	Mass of HMA, g	Specific Gravity of HMA
1	*2*	*3*	*4 = 2 + 3*	*5*	*6 = 5/4*
31	492.77	0.2046	492.975	1251.3	2.5383
30[a]	492.77	0.1860	492.956	1251.3	2.5384
29[a]	492.77	0.1674	492.937	1251.3	2.5385
28[a]	492.77	0.1488	492.919	1251.3	2.5386
27[a]	492.77	0.1302	492.900	1251.3	2.5386
26[a]	492.77	0.1116	492.882	1251.3	2.5387
25[a]	492.77	0.0930	492.863	1251.3	2.5388
24[a]	492.77	0.0744	492.844	1251.3	2.5389
23[a]	492.77	0.0558	492.826	1251.3	2.5390
22[a]	492.77	0.0372	492.807	1251.3	2.5391
21[a]	492.77	0.0186	492.789	1251.3	2.5392
20	492.77	0.0000	492.772	1251.3	2.5393
19	492.77	−0.0186	492.751	1251.3	2.5394

[a] Range less than 0.0005.

Notes: Strictly speaking, the above table shows that the specific gravity for this particular mix, as measured at 20°C (68°F), just fails to meet the corrected theoretical maximum specific gravity at 25°C (77°F), 2.5388 versus 2.5393, that is, by 0.0005, and that a temperature correction would be required. If the measurement for volume had been made at 21°C (70°F), the table indicates that no temperature correction would have been necessary, because the measurement at 21°C (70°F) would have satisfied the theoretical maximum specific gravity at 25°C (77°F), 2.5388 versus 2.5392, a difference of less than 0.0005.

[1] Sargent Welch, 39745 Gauge-Vacuum, Mercury Prefilled (or equivalent).

[2] Krebs and Walker, *Highway Materials*, McGraw-Hill, Inc., 1971, p. 274.

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Standard Method of Test for

Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus

AASHTO Designation: T 245-97 (2008)

1. SCOPE

1.1. This method covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixture loaded on the lateral surface by means of the Marshall apparatus. This method is for use with mixtures containing asphalt cement, asphalt cutback or tar, and aggregate up to 25.4-mm (1-in.) maximum size.

2. APPARATUS

2.1. *Specimen Mold Assembly*—Mold cylinders 101.6 mm (4 in.) in diameter by 76.2 mm (3 in.) in height, base plates, and extension collars shall conform to the details shown in Figure 1. Three mold cylinders are recommended.

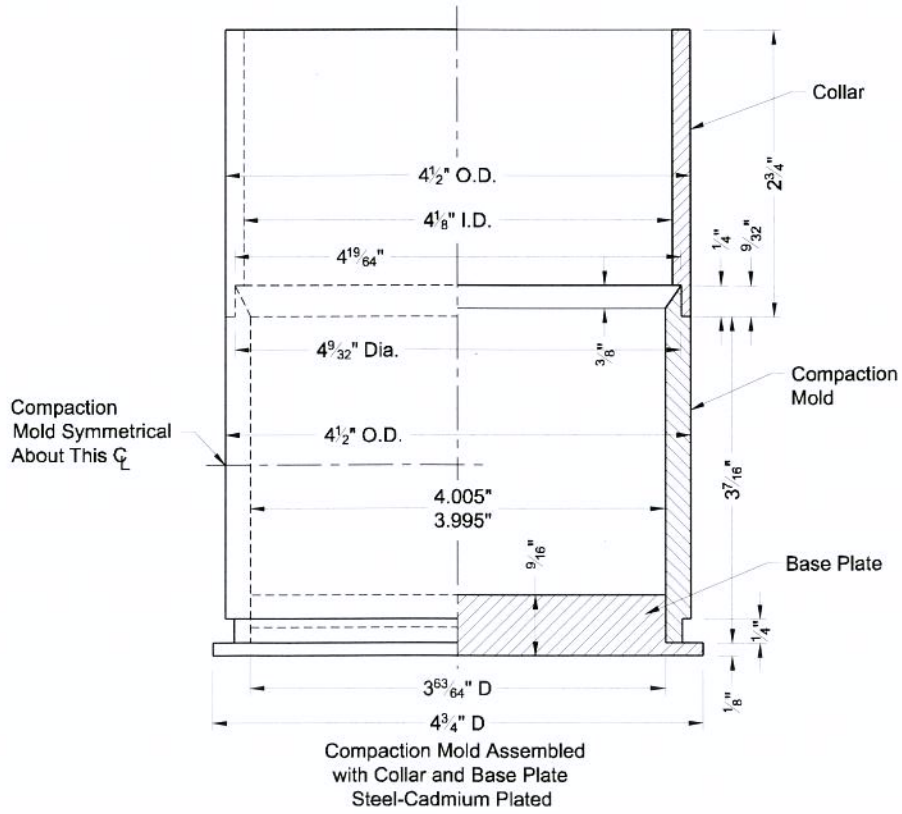

Figure 1—Compaction Mold

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Table 1—Table of Equivalents for Figures 1 and 3

Metric Equivalents, mm	U.S. Customary Units, in.	Metric Equivalents, mm	U.S. Customary Units, in.	Metric Equivalents, mm	U.S. Customary Units, in.	Metric Equivalents, mm	U.S. Customary Units, in.
0.11	0.005	17.5	$^{11}/_{16}$	58.7	$2^{5}/_{16}$	104.8	$4^{1}/_{8}$
0.8	$^{1}/_{32}$	19.0	$^{3}/_{4}$	63.5	$2^{1}/_{2}$	108.7	$4^{9}/_{32}$
1.6	$^{1}/_{16}$	22.2	$^{7}/_{8}$	69.8	$2^{3}/_{4}$	109.1	$4^{19}/_{64}$
3.2	$^{1}/_{8}$	23.8	$^{15}/_{16}$	73.0	$2^{7}/_{8}$	114.3	$4^{1}/_{2}$
4.8	$^{3}/_{16}$	25.4	1	76.2	3	117.5	$4^{5}/_{8}$
6.4	$^{1}/_{4}$	28.6	$1^{1}/_{8}$	82.6	$3^{1}/_{4}$	120.6	$4^{3}/_{4}$
7.1	$^{9}/_{32}$	31.8	$1^{1}/_{4}$	87.3	$3^{7}/_{16}$	128.6	$5^{1}/_{16}$
9.5	$^{3}/_{8}$	34.9	$1^{3}/_{8}$	98.4	$3^{7}/_{8}$	130.2	$5^{1}/_{8}$
12.6	0.496	38.1	$1^{1}/_{2}$	101.2	$3^{63}/_{64}$	146.0	$5^{3}/_{4}$
12.67	0.499	41.3	$1^{5}/_{8}$	101.35	3.990	152.4	6
12.7	$^{1}/_{2}$	44.4	$1^{3}/_{4}$	101.47	3.995	158.8	$6^{1}/_{4}$
14.3	$^{9}/_{16}$	50.8	2	101.6	4	193.7	$7^{5}/_{8}$
15.9	$^{5}/_{8}$	57.2	$2^{1}/_{4}$	101.73	4.005	685.8	27

2.2. *Specimen Extractor*—Steel, in the form of a disk with a diameter not less than 100 mm (3.95 in.) and 12.7 mm ($^{1}/_{2}$ in.) thick for extracting the compacted specimen from the specimen mold with the use of the mold collar. A suitable bar is required to transfer the load from the ring dynamometer adapter to the extension collar while extracting the specimen.

2.3. *Compaction Hammer*—The compaction hammer (Figure 2) shall have a flat, circular tamping face and a 4536 ± 9 g (10 ± 0.02 lb) sliding weight (including safety finger guard if so equipped) with a free fall of 457.2 ± 1.524 mm (18 ± 0.06 in.).

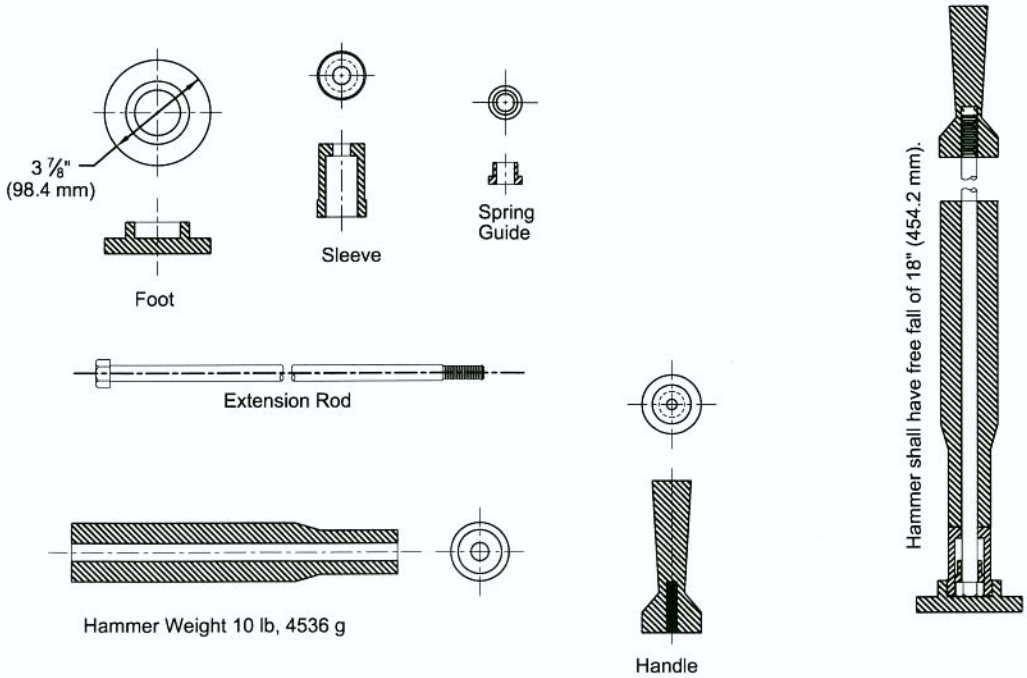

Figure 2—Compaction Hammer

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Note 1—The compaction hammer may be equipped with a finger safety guard as shown in Figure 2.

Note 2—Instead of a hand-operated hammer, and associated equipment described in Sections 2.3, 2.4, and 2.5, a mechanically operated hammer may be used provided it has been calibrated to give results comparable with the hand-operated hammer.

2.4. *Compaction Pedestal*—The compaction pedestal shall consist of a 203.2- by 203.2- by 457.2-mm (8- by 8- by 18-in.) wooden post capped with a 304.8- by 304.8- by 25.4-mm (12- by 12- by 1-in.) steel plate. The wooden post shall be oak, pine, or other wood having an average dry weight of 0.67 to 0.77 g/cm^3 (42 to 48 lb/ft^3). The wooden post shall be secured by four angle brackets to a solid concrete slab. The steel cap shall be firmly fastened to the post. The pedestal assembly shall be installed so that the post is plumb and the cap is level.

2.5. *Specimen Mold Holder*—Mounted on the compaction pedestal so as to center the compaction mold over the center of the post. It shall hold the compaction mold, collar, and base plate securely in position during compaction of the specimen.

2.6. *Breaking Head (Figure 3)*—Shall consist of upper and lower cylindrical segments or test heads having an inside radius of curvature of 50.8 mm (2 in.) accurately machined. The lower segment shall be mounted on a base having two perpendicular guide rods or posts extending upward. Guide sleeves in the upper segment shall be in such a position as to direct the two segments together without appreciable binding or loose motion on the guide rods.

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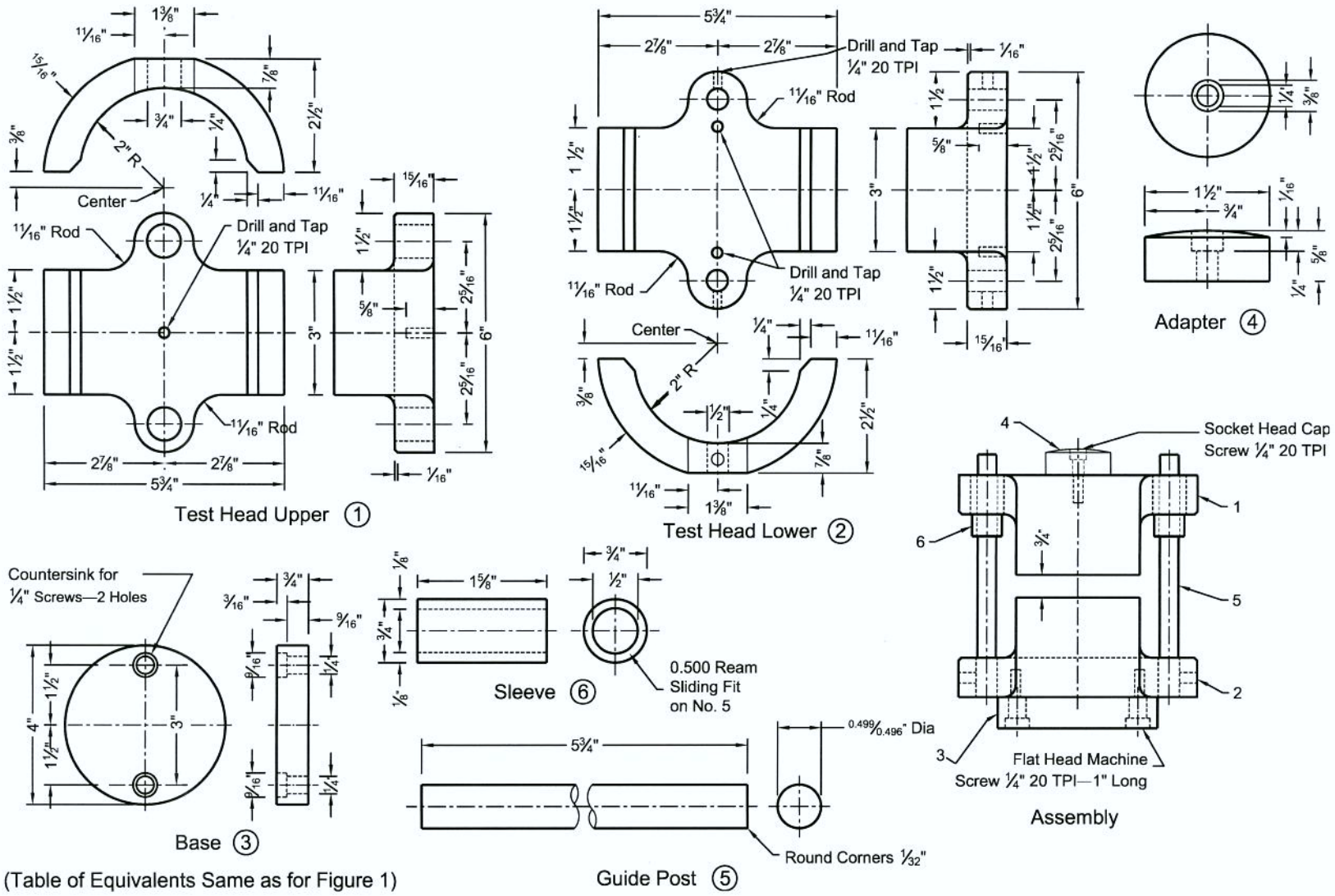

(Table of Equivalents Same as for Figure 1)

Figure 3—Breaking Head

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2.7. *Loading Jack*—The loading jack (Figure 4) shall consist of a screw jack mounted in a testing frame and shall produce a uniform vertical movement of 50.8 mm (2 in.)/min. An electric motor may be attached to the jacking mechanism.

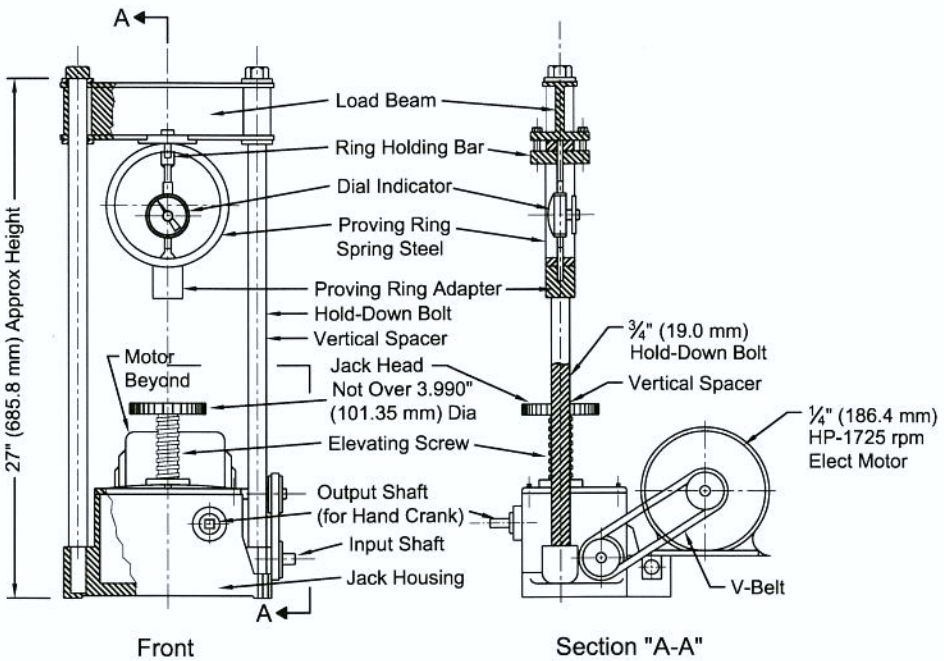

Figure 4—Compression Testing Machine

Note 3—Instead of the loading jack, a mechanical or hydraulic testing machine may be used provided the rate of movement can be maintained at 50.8 mm (2 in.)/min while the load is applied.

2.8. *Ring Dynamometer Assembly*—One-ring dynamometer (Figure 4) of 22.2 kN (5000 lbf) capacity and sensitivity of 44.5 N (10 lbf) up to 4.45 kN (1000 lbf) and 111.2N (25 lbf) between 4.45 and 22.2 kN (1000 and 5000 lbf) shall be equipped with a micrometer dial. The micrometer dial shall be graduated in 0.0025 mm (0.0001 in.). Upper and lower ring dynamometer attachments are required for fastening the ring dynamometer to the testing frame and transmitting the load to the breaking head.

Note 4—Instead of the ring dynamometer assembly, any suitable load-measuring device may be used provided the capacity and sensitivity meet the above requirements.

2.9. *Flowmeter*—The flowmeter shall consist of a guide sleeve and a gauge. The activating pin of the gauge shall slide inside the guide sleeve with a slight amount of frictional resistance. The guide sleeve shall slide freely over the guide rod of the breaking head. The flowmeter gauge shall be adjusted to zero when placed in position on the breaking head when each individual test specimen is inserted between the breaking head segments. Graduations of the flowmeter gauge shall be in 0.25-mm (0.01-in.) divisions.

Note 5—Instead of the flowmeter, a micrometer dial or stress-strain recorder graduated in 0.25 mm (0.01 in.) may be used to measure flow.

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2.10. *Ovens or Hot Plates*—Ovens or hot plates shall be provided for heating aggregates, bituminous material, specimen molds, compaction hammers, and other equipment to the required mixing and molding temperatures. It is recommended that the heating units be thermostatically controlled so as to maintain the required temperature within 2.8°C (5°F). Suitable shields, baffle plates, or sand baths shall be used on the surfaces of the hot plates to minimize localized overheating.

2.11. *Heating Device*—A small hot plate with continuously variable heating rate, a sand bath, infrared lamp, or other suitable device shall be available for supplying sufficient heat under the mixing bowl to maintain the aggregate and bituminous material at the desired temperature during mixing. If a hot plate is used, a wire mesh or similar material shall be placed on the hot plate to prevent direct contact between the hot plate and mixing bowl.

2.12. *Mixing Apparatus*—Mechanical mixing is recommended. Any type of mechanical mixer may be used provided it can be maintained at the required mixing temperature and will produce a well-coated, homogeneous mixture of the required amount in the allowable time, and further provided that essentially all of the batch can be recovered. A metal pan or bowl of sufficient capacity and hand mixing may also be used.

2.13. *Water Bath*—The water bath shall be at least 152.4 mm (6 in.) deep and shall be thermostatically controlled so as to maintain the bath at 60 ± 1°C (140 ± 2°F) or 37.8 ± 1°C (100 ± 2°F). The tank shall have a perforated false bottom or be equipped with a shelf for supporting specimens 50.8 mm (2 in.) above the bottom of the bath.

2.14. *Air Bath*—The air bath for asphalt cutback mixtures shall be thermostatically controlled and shall maintain the air temperature at 25 ± 1°C (77° ± 2°F).

2.15. *Miscellaneous Equipment*:

2.15.1. *Containers for Heating Aggregates*—flat-bottom metal pans or other suitable containers.

2.15.2. *Containers for Heating Bituminous Material*—either gill-type tins, beakers, pouring pots, or saucepans may be used.

2.15.3. *Mixing Tool*—either a steel trowel (garden type) or spatula for spading and hand mixing.

2.15.4. *Thermometers*—for determining temperatures of aggregates, bitumen, and bituminous mixtures. Armored-glass, dial type, or digital thermometers with metal stems are recommended. A range from 9.9 to 204°C (50 to 400°F) with sensitivity of 2.8°C (5°F) is required.

2.15.5. Thermometers for water and air baths sensitive to 0.2°C (0.4°F) with a range sufficient to determine the specified bath temperature.

2.15.6. *Balance*—2-kg capacity, sensitive to 0.1 g, for weighing molded specimens.

2.15.7. *Balance*—5-kg capacity, sensitive to 1.0 g, for batching mixtures.

2.15.8. *Gloves*—for handling hot equipment.

2.15.9. *Rubber Gloves*—for removing specimens from water bath.

2.15.10. *Marking Crayons*—for identifying specimens.

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2.15.11. *Scoop*—flat bottom, for batching aggregates.

2.15.12. *Spoon*—large, for placing the mixture in the specimen molds.

3. TEST SPECIMENS

3.1. *Number of Specimens*—Prepare at least three specimens for each combination of aggregates and bitumen content.

3.2. *Preparation of Aggregates*—Dry aggregates to constant mass at 105 to 110°C (221 to 230°F) and separate the aggregates by dry-sieving into the desired size fractions.[1] The following size fractions are recommended:

- 25.0 to 19.0 mm (1 to $^3/_4$ in.)
- 19.0 to 9.5 mm ($^3/_4$ to $^3/_8$ in.)
- 9.5 mm to 4.75 mm ($^3/_8$ in. to No. 4)
- 4.75 mm to 2.36 mm (No. 4 to No. 8)
- Passing 2.36 mm (No. 8)

3.3. *Determination of Mixing and Compacting Temperatures*:

3.3.1. The temperatures to which the asphalt cement and asphalt cutback must be heated to produce a viscosity of 170 ± 20 cSt shall be the mixing temperature.

3.3.2. The temperature to which asphalt cement must be heated to produce a viscosity of 280 ± 30 cSt shall be the compacting temperature.

3.3.3. From a composition chart for the asphalt cutback used, determine from its viscosity at 60°C (140°F) the percentage of solvent by mass. Also determine from the chart the viscosity at 60°C (140°F) of the asphalt cutback after it has lost 50 percent of its solvent. The temperature determined from the viscosity temperature chart to which the asphalt cutback must be heated to produce a viscosity of 280 ± 30 cSt after a loss of 50 percent of the original solvent content shall be the compacting temperature.

3.3.4. The temperature to which tar must be heated to produce Engler specific viscosities of 25 ± 3 and 40 ± 5 shall be, respectively, the mixing and compacting temperature.

3.4. *Preparation of Mixtures*:

3.4.1. An initial batch shall be mixed for the purpose of "buttering" the mixture bowl and stirrers. This batch shall be emptied after mixing and the sides of the bowl and stirrers shall be cleaned of mixture residue by scraping with a small limber spatula but shall not be wiped with cloth or washed clean with solvent, except when a change is to be made in the binder or at the end of a run.

3.4.2. Weigh into separate pans for each test specimen the amount of each size fraction required to produce a batch that will result in a compacted specimen 63.5 ± 1.27 mm (2.5 ± 0.05 in.) in height (about 1200 g). Mix the aggregate in each pan and place the pans on a hot plate or in the oven and heat to a temperature not exceeding the mixing temperature established in Section 3.3 by more than approximately 28°C (50°F) for asphalt cement and tar mixes at 14°C (25°F) for cutback asphalt mixes. Heat, to the established mixing temperature, just sufficient bituminous material for the batch in a separate container. Charge the mixing bowl with the heated aggregate. Form a crater in the dry-blended aggregate and weigh the preheated required amount of bituminous material into

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the mixture. For mixes prepared with cutback asphalt, introduce the mixing blade in the mixing bowl and determine the total mass of the mix components plus bowl and blade before proceeding with mixing. Care must be exercised to prevent loss of the mix during mixing and subsequent handling. At this point, the temperature of the aggregate and bituminous material shall be within the limits of the mixing temperature established in Section 3.3. Mix the aggregate and bituminous material rapidly until thoroughly coated. To maintain proper mixing temperature, one of the methods described in Section 2.11 may be used.

3.4.3. Following mixing, cure asphalt cutback mixtures in a ventilated oven maintained at approximately 11.1°C (20°F) above the compaction temperature. Curing is to be continued in the mixing bowl until the precalculated weight of 50 percent solvent loss or more has been obtained. The mix may be stirred in a mixing bowl during curing to accelerate the solvent loss. However, care should be exercised to prevent loss of the mix. Weigh the mix during curing in successive intervals of 15 minutes initially and less than 10-minute intervals as the weight of the mix at 50 percent solvent loss is approached.

3.5. *Compaction of Specimens*:

3.5.1. Thoroughly clean the specimen mold assembly and the face of the compaction hammer and heat them either in boiling water, on the hot plate, or in an oven, to a temperature between 93.3 and 148.9°C (200 and 300°F). Place a piece of filter paper or paper toweling cut to size in the bottom of the mold before the mixture is introduced. Place the entire batch in the mold, and spade the mixture vigorously with a heated spatula or trowel 15 times around the perimeter and 10 times over the interior. Remove the collar and smooth the surface of the mix with a trowel to a slightly rounded shape. Temperatures of the mixtures immediately prior to compaction shall be within the limits of the compacting temperature established in Section 3.3.

3.5.2. Replace the collar, then place a piece of filter paper or paper toweling cut to size on top of the mixture and place the mold assembly on the compaction pedestal in the mold holder, and unless otherwise specified, apply 50 or 75 blows with the compaction hammer with a free fall in 457.2 mm (18 in.). Hold the axis of the compaction hammer perpendicular to the base of the mold assembly during compaction. Remove the base plate and collar, and reverse and reassemble the mold. Apply the same number of compaction blows to the face of the reversed specimen. After compaction, remove the base plate and place the sample extractor on the end of the specimen. Place the assembly with the extension collar up in the testing machine, apply pressure to the collar by means of the load transfer bar, and force the specimen into the extension collar. Lift the collar from the specimen. Carefully transfer the specimen to a smooth, flat surface and allow it to stand overnight at room temperature. Weigh, measure, and test the specimen.

Note 6—In general, specimens shall be cooled as specified in Section 3.5.2. When more rapid cooling is desired, table fans may be used. Mixtures that lack sufficient cohesion to result in the required cylindrical shape on removal from the mold immediately after compaction may be cooled in the mold in air until sufficient cohesion has developed to result in the proper cylindrical shape.

4. PROCEDURE

4.1. Bring the specimens prepared with asphalt cement or tar to the specified temperature by immersing in the water bath 30 to 40 minutes or placing in the oven for 2 hours. Maintain the bath or oven temperature at 60 ± 1°C (140 ± 1.8°F) for the asphalt cement specimens and 37.8 ± 1°C (100 ± 1.8°F) for tar specimens. Bring the specimens prepared with asphalt cutback to the specified temperature by placing them in the air bath for a minimum of 2 hours. Maintain the air bath temperature at 25 ± 1°C (77 ± 1.8°F). Thoroughly clean the guide rods and the inside surfaces of the test heads prior to making the test, and lubricate the guide rods so that the upper test head slides freely over them. The testing-head temperature shall be maintained between 21.1 to 37.8°C

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(70 to 100°F) using a water bath when required. Remove the specimen from the water bath, oven, or air bath, and place in the lower segment of the breaking head. Place the upper segment of the breaking head on the specimen, and place the complete assembly in position on the testing machine. Place the flowmeter, where used, in position over one of the guide rods and adjust the flowmeter to zero while holding the sleeve firmly against the upper segment of the breaking head. Hold the flowmeter sleeve firmly against the upper segment of the breaking head while the test load is being applied.

4.2. Apply the load to the specimen by means of the constant rate of movement of the loadjack or testing-machine head of 50.8 mm (2 in.) per minute until the maximum load is reached and the load decreases as indicated by the dial. Record the maximum load noted on the testing machine or converted from the maximum micrometer dial reading. Release the flowmeter sleeve or note the micrometer dial reading, where used, the instant the maximum load begins to decrease. Note and record the indicated flow value or equivalent units in twenty-five hundredths of a millimeter (hundredths of an inch) if a micrometer dial is used to measure the flow. The elapsed time for the test from removal of the test specimen from the water bath to the maximum load determination shall not exceed 30 seconds.

Note 7—For core specimens, correct the load when thickness is other than 63.5 mm ($2^1/_2$ in.) by using the proper multiplying factor from Table 2.

5. REPORT

5.1. *The report shall include the following information*:

5.1.1. Type of sample tested (laboratory sample or pavement core specimen);

Note 8—For core specimens, the height of each test specimen in millimeters (or inches) shall be reported.

5.1.2. Average maximum load in pounds-force (or newtons) of at least three specimens, corrected when required;

5.1.3. Average flow value, in hundredths of an inch, twenty-five hundredths of a millimeter, of three specimens; and

5.1.4. Test temperature.

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Table 2—Stability Correlation Ratios[a,b]

Volume of Specimen, cm^3	Approximate Thickness of Specimen, in.	mm	Correlation Ratio
200 to 213	1	25.4	5.56
214 to 225	$1^1/_{16}$	27.0	5.00
226 to 237	$1^1/_8$	28.6	4.55
238 to 250	$1^3/_{16}$	30.2	4.17
251 to 264	$1^1/_4$	31.8	3.85
265 to 276	$1^5/_{16}$	33.3	3.57
277 to 289	$1^3/_8$	34.9	3.33
290 to 301	$1^7/_{16}$	36.5	3.03
302 to 316	$1^1/_2$	38.1	2.78
317 to 328	$1^9/_{16}$	39.7	2.50
329 to 340	$1^5/_8$	41.3	2.27
341 to 353	$1^{11}/_{16}$	42.9	2.08
354 to 367	$1^3/_4$	44.4	1.92
368 to 379	$1^{13}/_{16}$	46.0	1.79
380 to 392	$1^7/_8$	47.6	1.67
393 to 405	$1^{15}/_{16}$	49.2	1.56
406 to 420	2	50.8	1.47
421 to 431	$2^1/_{16}$	52.4	1.39
432 to 443	$2^1/_8$	54.0	1.32
444 to 456	$2^3/_{16}$	55.6	1.25
457 to 470	$2^1/_4$	57.2	1.19
471 to 482	$2^5/_{16}$	58.7	1.14
483 to 495	$2^3/_8$	60.3	1.09
496 to 508	$2^7/_{16}$	61.9	1.04
509 to 522	$2^1/_2$	63.5	1.00
523 to 535	$2^9/_{16}$	65.1	0.96
536 to 546	$2^5/_8$	66.7	0.93
547 to 559	$2^{11}/_{16}$	68.3	0.89
560 to 573	$2^3/_4$	69.9	0.86
574 to 585	$2^{13}/_{16}$	71.4	0.83
586 to 598	$2^7/_8$	73.0	0.81
599 to 610	$2^{15}/_{16}$	74.6	0.78
611 to 625	3	76.2	0.76

[a] The measured stability of a specimen multiplied by the ratio for the thickness of the specimen equals the corrected stability for a 63.5-mm ($2^1/_2$-in.) specimen.

[b] Volume-thickness relationship is based on a specimen diameter of 101.6 mm (4 in.).

[1] Detailed requirements for these sieves are given in M 92, Wire-Cloth Sieves for Testing Purposes.

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Standard Method of Test for

Reducing Samples of Aggregate to Testing Size

AASHTO Designation: T 248-11[1]
ASTM Designation: C 702-98 (2003)

1. SCOPE

1.1. These methods cover the reduction of large samples of aggregate to the appropriate size for testing, employing techniques that are intended to minimize variations in measured characteristics between the test samples so selected and the large sample.

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard does not purport to address the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 2, Sampling of Aggregates
- T 84, Specific Gravity and Absorption of Fine Aggregate

2.2. *ASTM Standard*:

- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates

3. TERMINOLOGY

3.1. *definitions*—the terms used in this standard are defined in ASTM C 125.

4. SIGNIFICANCE AND USE

4.1. Specifications for aggregates require sampling portions of the material for testing. Other factors being equal, larger samples will tend to be more representative of the total supply. The methods described in this standard provide for reducing the large sample obtained in the field or produced in the laboratory to a convenient size for conducting a number of tests to describe the material and measure its quality. These methods are conducted in such a manner that the smaller test sample portion will be representative of the larger sample and, thus, of the total supply. The individual test methods provide for minimum masses of material to be tested.

4.2. Under certain circumstances, reduction in size of the large sample prior to testing is not recommended. Substantial differences between the selected test samples sometimes cannot be

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avoided, as for example, in the case of an aggregate having relatively few large-sized particles in the sample. The laws of chance dictate that these few particles may be unequally distributed among the reduced-size test samples. Similarly, if the test sample is being examined for certain contaminants occurring as a few discrete fragments in only small percentages, caution should be used in interpreting results from the reduced-size test sample. Chance inclusion or exclusion of only one or two particles in the selected test sample may importantly influence interpretation of the characteristics of the original sample. In these cases, the entire original sample should be tested.

4.3. Failure to carefully follow the procedures in these methods could result in providing a nonrepresentative sample to be used in subsequent testing.

5. SELECTION OF METHOD

5.1. *Fine Aggregate*—Samples of fine aggregate that are drier than the saturated-surface-dry condition (Note 1) shall be reduced in size by a mechanical splitter according to Method A. Samples having free moisture on the particle surfaces may be reduced in size by quartering according to Method B, or by treating as a miniature stockpile as described in Method C.

5.1.1. If the use of Method B or Method C is desired, and the sample does not have free moisture on the particle surfaces, the sample may be moistened to achieve this condition, thoroughly mixed, and then the sample reduction performed.

Note 1—The method of determining the saturated-surface-dry condition is described in T 84. As a quick approximation, if the fine aggregate will retain its shape when molded in the hand, it may be considered to be wetter than saturated-surface-dry.

5.1.2. If use of Method A is desired and the sample has free moisture on the particle surfaces, the entire sample may be dried to at least the surface-dry condition, using temperatures that do not exceed those specified for any of the tests contemplated, and then the sample reduction performed. Alternatively, if the moist sample is very large, a preliminary split may be made using a mechanical splitter having wide chute openings 38 mm ($1^1/_2$ in.) or more to reduce the sample to not less than 5000 g. The portion so obtained is then dried, and reduction to test sample size is completed using Method A.

5.2. *Coarse Aggregates and Mixtures of Coarse and Fine Aggregates*—Reduce the sample using a mechanical splitter in accordance with Method A (preferred method) or by quartering in accordance with Method B. The miniature stockpile Method C is not permitted for coarse aggregates or mixtures of coarse and fine aggregates.

6. SAMPLING

6.1. The samples of aggregate obtained in the field shall be taken in accordance with T 2, or as required by individual test methods. When tests for sieve analysis only are contemplated, the size of field sample listed in T 2 is usually adequate. When additional tests are to be conducted, the user shall determine that the initial size of the field sample is adequate to accomplish all intended tests. Similar procedures shall be used for aggregate produced in the laboratory.

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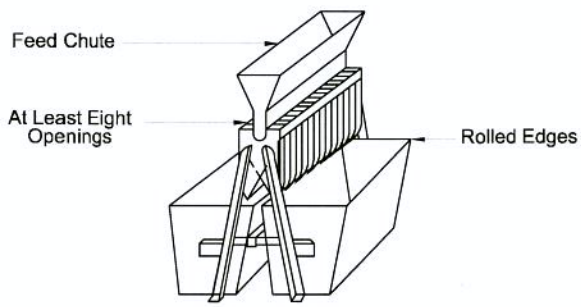
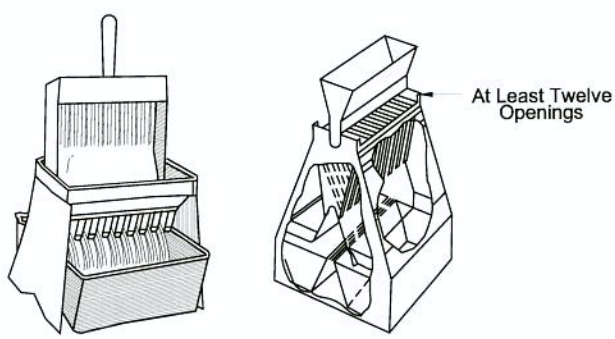
METHOD A—MECHANICAL SPLITTER

7. APPARATUS

7.1. *Sample Splitter*—Sample splitters shall have an even number of equal width chutes, but not less than a total of eight for coarse aggregate, or 12 for fine aggregate, which discharge alternatively to each side of the splitter. For coarse aggregate and mixed aggregate the minimum width of the individual chutes shall be approximately 50 percent larger than the largest particles in the sample to be split (Note 2). For dry fine aggregate in which the entire sample will pass the 9.5-mm ($^3/_8$-in.) sieve, the minimum width of the individual chutes shall be at least 50 percent larger than the largest particles in the sample and the maximum width shall be 19 mm ($^3/_4$ in.). The splitter shall be equipped with two receptacles to hold the two halves of the sample following splitting. It shall also be equipped with a hopper or straightedged pan, which has a width equal to or slightly less than the overall width of the assembly of chutes, by which the sample may be fed at a controlled rate to the chutes. The splitter and accessory equipment shall be so designed that the sample will flow smoothly without restriction or loss of material (Figure 1).



Riffle Sample Splitter
(a) Large Sample Splitter for Coarse Aggregate



(b) Small Sample Splitters for Fine Aggregate

Note: (a) may be constructed as either closed or open type. Closed type is preferred.

Figure 1—Sample Splitters (Riffles)

Note 2—Mechanical splitters are commonly available in sizes adequate for coarse aggregate having the largest particle not over 37.5 mm ($1^1/_2$ in.).

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8. PROCEDURE

8.1. Place the original sample in the hopper or pan and uniformly distribute it from edge to edge, so that when it is introduced into the chutes, approximately equal amounts will flow through each chute. The rate at which the sample is introduced shall be such as to allow free flowing through the chutes into the receptacles below. Reintroduce the portion of the sample in one of the receptacles into the splitter as many times as necessary to reduce the sample to the size specified for the intended test. The portion of the material collected in the other receptacle may be reserved for reduction in size for other tests.

METHOD B—QUARTERING

9. APPARATUS

9.1. Apparatus shall consist of a straightedge; straightedged scoop, shovel or trowel; a broom or brush; and a canvas blanket or tear-resistant tarp approximately 2 by 2.5 m (6 by 8 ft).

10. PROCEDURE

10.1. Use either the procedure described in Section 10.1.1 or 10.1.2, or a combination of both.

10.1.1. Place the original sample on a hard, clean, level surface where there will be neither loss of material nor the accidental addition of foreign material. Mix the material by turning the entire sample over at least three times until the material is thoroughly mixed. With the last turning, form the entire sample into a conical pile by depositing individual lifts on top of the preceding lift. Carefully flatten the conical pile to a uniform thickness and diameter by pressing down the apex with a shovel or trowel so that each quarter sector of the resulting pile will contain the material originally in it. The diameter should be approximately four to eight times the thickness. Divide the flattened mass into four equal quarters with a shovel or trowel and remove two diagonally opposite quarters, including all fine material, and brush the cleared spaces clean. The two unused quarters may be set aside for later use or testing, if desired. Successively mix and quarter the remaining material until the sample is reduced to the desired size (Figure 2).

10.1.2. As an alternative to the procedure in Section 10.1.1 or when the floor surface is uneven, the field sample may be placed on a canvas blanket or tear-resistant tarp and mixed with a shovel or trowel as described in Section 10.1.1, leaving the sample in a conical pile. As an alternative to mixing with the shovel or trowel, lift each corner of the blanket or tarp and pull it over the sample toward the diagonally opposite corner, causing the material to be rolled. After the material has been rolled a sufficient number of times so that it is thoroughly mixed, pull each corner of the blanket or tarp toward the center of the pile so the material will be left in a conical pile. Flatten the pile as described in Section 10.1.1. Divide the sample as described in Section 10.1.1, or insert a stick or pipe beneath the blanket or tarp and under the center of the pile, then lift both ends of the stick, dividing the sample into two equal parts. Remove the stick, leaving a fold of the blanket between the divided portions. Insert the stick under the center of the pile at right angles to the first division and again lift both ends of the stick, dividing the sample into four equal parts. Remove two diagonally opposite quarters, being careful to clean the fines from the blanket or tarp. The two unused quarters may be set aside for later use or testing, if desired. Successively mix and quarter the remaining material until the sample is reduced to the desired size (Figure 3).

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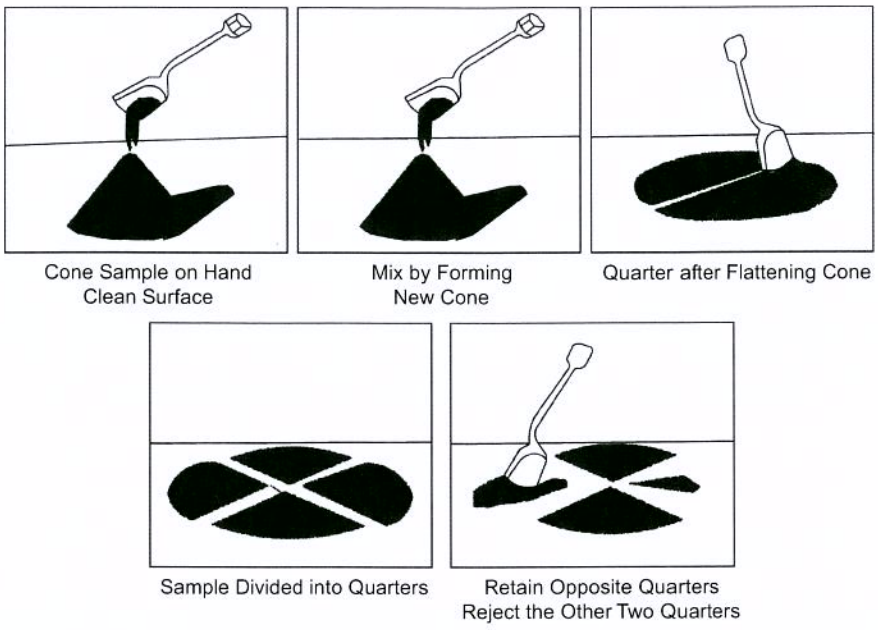

Figure 2—Quartering on a Hard, Clean, Level Surface

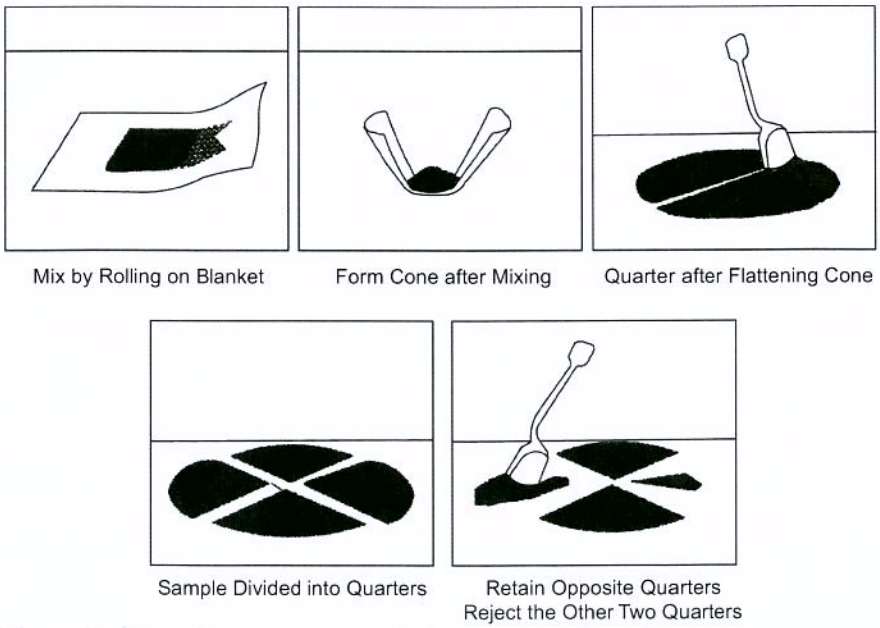

Figure 3—Quartering on a Canvas Blanket or Tear-Resistant Tarp

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METHOD C—MINIATURE STOCKPILE SAMPLING (DAMP FINE AGGREGATE ONLY)

11. APPARATUS

11.1. Apparatus shall consist of a straightedge; straightedged scoop, shovel, or trowel for mixing the aggregate; and either a small sampling thief, small scoop, or spoon for sampling.

12. PROCEDURE

12.1. Place the original sample of damp fine aggregate on a hard, clean, level surface where there will be neither loss of material nor the accidental addition of foreign material. Mix the material by turning the entire sample over at least three times until the material is thoroughly mixed. With the last turning, form the entire sample into a conical pile by depositing individual lifts on top of the preceding lift. If desired, the conical pile may be flattened to a uniform thickness and diameter by pressing the apex with a shovel or trowel so that each quarter sector of the resulting pile will contain the material originally in it. Obtain a sample for each test by selecting at least five increments of material at random locations from the miniature stockpile, using any of the sampling devices described in Section 11.1.

[1] Technically equivalent but not identical to ASTM C 702-98 (2003).

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Standard Method of Test for

Total Evaporable Moisture Content of Aggregate by Drying

AASHTO Designation: T 255-00 (2008)[1]
ASTM Designation: C 566-97 (2004)

1. SCOPE

1.1. This test method covers the determination of the percentage of evaporable moisture in a sample of aggregate by drying both surface moisture and moisture in the pores of the aggregate. Some aggregate may contain water that is chemically combined with the minerals in the aggregate. Such water is not evaporable and is not included in the percentage determined by this test method.

1.2. The values stated in SI units are to be regarded as the standard. The values stated in parentheses are provided for information only.

1.3. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements, see Sections 5.3.1, 7.2.1, and 7.3.1.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- R 16, Regulatory Information for Chemicals Used in AASHTO Tests
- T 2, Sampling of Aggregates
- T 19M/T 19, Bulk Density ("Unit Weight") and Voids in Aggregate
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate

2.2. *ASTM Standards*:

- C 125, Standard Terminology Relating to Concrete and Concrete Aggregates
- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. For definitions of terms used in this test method, refer to ASTM C 125.

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4. SIGNIFICANCE AND USE

4.1. This test method is sufficiently accurate for usual purposes such as adjusting batch quantities of ingredients for concrete. It will generally measure the moisture in the test sample more reliably than the sample can be made to represent the aggregate supply. In rare cases where aggregate itself is altered by heat, or where more refined measurement is required, the test should be conducted using a ventilated, controlled-temperature oven.

4.2. Large particles of coarse aggregate, especially those larger than 50 mm (2 in.), will require greater time for the moisture to travel from the interior of the particle to the surface. The user of this test method should determine by trial if rapid drying methods provide sufficient accuracy for the intended use when drying large-size particles.

5. APPARATUS

5.1. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.

5.2. *Source of Heat*—A ventilated oven capable of maintaining the temperature surrounding the sample at 110 ± 5°C (230 ± 9°F). Where close control of the temperature is not required (see Section 4.1), other suitable sources of heat may be used, such as an electric or gas hot plate, electric heat lamps, or a ventilated microwave oven.

5.3. *Sample Container*—A container not affected by the heat, and of sufficient volume to contain the sample without danger of spilling, and of such shape that the depth of sample will not exceed one-fifth of the least lateral dimension.

5.3.1. **Precaution**—When a microwave oven is used, the container shall be nonmetallic.

Note 1—Except for testing large samples, an ordinary frying pan is suitable for use with a hot plate, or any shallow flat-bottomed metal pan with heat lamps or oven. Note precaution in Section 5.3.1.

5.4. *Stirrer*—A metal spoon or spatula of convenient size.

6. SAMPLE

6.1. Sampling shall generally be accomplished in accordance with T 2, except the sample size may be as stated in Table 1.

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Table 1—Sample Size for Aggregate

Nominal Maximum Size of Aggregate, mm (in.)[a]	Mass of Normal Weight Aggregate Sample, Min., kg[b]
4.75 (0.187) (No. 4)	0.5
9.5 (3/8)	1.5
12.5 (1/2)	2
19.0 (3/4)	3
25.0 (1)	4
37.5 (1 1/2)	6
50 (2)	8
63 (2 1/2)	10
75 (3)	13
90 (3 1/2)	16
100 (4)	25
150 (6)	50

[a] Based on sieves meeting M 92.

[b] Determine the minimum sample mass for lightweight aggregate by multiplying the value listed by the dry-loose unit mass of the aggregate in kg/m3 (determined using T 19M/T 19) and dividing by 1600.

6.2. Secure a sample of the aggregate representative of the moisture content in the supply being tested and having a mass not less than the amount listed in Table 1. Protect the sample against loss of moisture prior to determining the mass.

7. PROCEDURE

7.1. Determine the mass of the sample to the nearest 0.1 percent.

7.2. Dry the sample thoroughly in the sample container by means of the selected source of heat, exercising care to avoid loss of any particles. Very rapid heating may cause some particles to explode, resulting in loss of particles. Use a controlled temperature oven when excessive heat may alter the character of the aggregate, or where more precise measurement is required. If a source of heat other than the controlled temperature oven is used, stir the sample during drying to accelerate the operation and avoid localized overheating. When using a microwave oven, stirring of the sample is optional.

7.2.1. ***Caution***—When using a microwave oven, occasionally minerals are present in aggregates that may cause the material to overheat and explode. If this occurs, it can damage the microwave oven.

7.3. When a hot plate is used, drying can be expedited by the following procedure. Add sufficient anhydrous denatured alcohol to cover the moist sample. Stir and allow suspended material to settle. Decant as much of the alcohol as possible without losing any of the sample. Ignite the remaining alcohol and allow it to burn off during drying over the hot plate.

7.3.1. ***Warning***—Exercise care to control the ignition operation to prevent injury or damage from the burning alcohol.

7.4. The sample is thoroughly dry when further heating causes, or would cause, less than 0.1 percent additional loss in mass.

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7.5. Determine the mass of the dried sample to the nearest 0.1 percent after it has cooled sufficiently not to damage the balance.

8. CALCULATION

8.1. Calculate total evaporable moisture content as follows:

$$p = 100(W - D)/D \qquad (1)$$

where:

p = total evaporable moisture content of sample, percent;

W = mass of original sample, g; and

D = mass of dried sample, g.

8.2. Surface moisture content is equal to the difference between the total evaporable moisture content and the absorption, with all values based on the mass of a dry sample. Absorption may be determined in accordance with T 85, Test for Specific Gravity and Absorption of Coarse Aggregate, or T 84, Test for Specific Gravity and Absorption of Fine Aggregate.

9. PRECISION AND BIAS

9.1. *Precision*:

9.1.1. The within-laboratory single operator standard deviation for moisture content of aggregates has been found to be 0.28 percent (Note 2). Therefore, results of two properly conducted tests by the same operator in the same laboratory on the same type of aggregate sample should not differ by more than 0.79 percent (Note 2) from each other.

9.1.2. The between-laboratory standard deviation for moisture content of aggregates has been found to be 0.28 percent (Note 2). Therefore, results of properly conducted tests from two laboratories on the same aggregate sample should not differ by more than 0.79 percent (Note 2) from each other.

9.1.3. Test data used to derive the above precision indices were obtained from samples dried to a constant mass in a drying oven maintained at 110 ± 5°C. When other drying procedures are used, the precision of the results may be significantly different than that indicated above.

Note 2—These numbers represent, respectively, the 1s and d2s limits as described in ASTM C 670.

9.2. *Bias*:

9.2.1. When experimental results are compared with known values from accurately compounded specimens, the following has been derived.

9.2.1.1. The bias of moisture tests on one aggregate material has been found to have a mean of +0.06 percent. The bias of individual test values from the same aggregate material has been found with 95 percent confidence to lie between –0.07 percent and +0.20 percent.

9.2.1.2. The bias of moisture tests on a second aggregate material has been found to have a mean of less than +0.01 percent. The bias of individual test values from the same aggregate material has been found with 95 percent confidence to lie between –0.14 percent and +0.14 percent.

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9.2.1.3. The bias of moisture tests overall on both aggregate materials has been found to have a mean of +0.03 percent. The bias of individual test values overall from both aggregate materials has been found with 95 percent confidence to lie between –0.12 percent and +0.18 percent.

9.2.2. Test data used to derive the above bias statement were obtained from samples dried to a constant mass in a drying oven maintained at 110 ± 5°C. When other drying procedures are used, the bias of the results may be significantly different than that indicated above.

Note 3—These precision and bias statements were derived from aggregate moisture data provided by 17 laboratories participating in the SHRP Soil Moisture Proficiency Sample Program, which is fully described in the National Research Council Report SHRP-P-619. The samples tested that relate to these statements were well-graded mixtures of fine and coarse aggregate with moisture contents ranging from air dry to saturated surface-dry.

10. KEYWORDS

10.1. Aggregate; drying; moisture content.

[1] This method is technically equivalent with ASTM C 566-97 (2004), except for the balance statement in Section 5.1.

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Standard Method of Test for

Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method

AASHTO Designation: T 308-10

1. SCOPE

1.1. This test method covers the determination of asphalt binder content of hot mix asphalt (HMA) by ignition at temperatures that reach the flashpoint of the binder in a furnace. The means of specimen heating may be the convection method or the direct infrared (IR) irradiation method. The aggregate remaining after burning can be used for sieve analysis using T 30.

1.2. The values stated in SI units are to be regarded as the standard.

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

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 231, Weighing Devices Used in the Testing of Materials
- R 47, Reducing Samples of Hot Mix Asphalt (HMA) to Testing Size
- T 2, Sampling of Aggregates
- T 30, Mechanical Analysis of Extracted Aggregate
- T 40, Sampling Asphalt Materials
- T 168, Sampling Bituminous Paving Mixtures
- T 248, Reducing Samples of Aggregate to Testing Size
- T 329, Moisture Content of Hot Mix Asphalt (HMA) by Oven Method

2.2. *Other Document*:

- Manufacturer's Instruction Manual

3. SUMMARY OF TEST METHOD

3.1. The asphalt binder in the HMA is ignited using the furnace equipment applicable to the particular method. This procedure covers two methods. Method A requires an ignition furnace with an internal balance. Method B requires an ignition furnace with an external balance.

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3.2. The asphalt binder content is calculated as the difference between the initial mass of the HMA and the mass of the residual aggregate, with adjustments for an asphalt binder correction factor and the moisture content. The asphalt binder content is expressed as a mass percent of the moisture-free mixture. This method may be affected by the type of aggregate in the mixture. Accordingly, to optimize accuracy, correction factors for asphalt binder and aggregate will be established by testing a set of correction factor specimens for each type of HMA. Correction factors must be determined before any acceptance testing is performed.

4. SIGNIFICANCE AND USE

4.1. This method can be used for quantitative determinations of asphalt binder content and gradation in HMA and pavement specimens for quality control, specification acceptance, and mixture evaluation studies. This method does not require the use of solvents. Aggregate obtained by this test method may be used for gradation analysis according to T 30.

5. APPARATUS

5.1. *Ignition Furnace*—A forced-air ignition furnace that heats the specimens by either the convection or direct IR irradiation method. The convection-type furnace must be capable of maintaining the temperature at 578°C (1072°F). The furnace chamber dimensions shall be adequate to accommodate a specimen size of 3500 g. The furnace door shall be equipped so that the door cannot be opened during the ignition test. A method for reducing furnace emissions shall be provided. The furnace shall be vented into a hood or to the outside and, when set up properly, shall have no noticeable odors escaping into the laboratory. The furnace shall have a fan with the capability to pull air through the furnace to expedite the test and reduce the escape of smoke into the laboratory.

5.1.1. For Method A, the furnace shall also have an internal balance thermally isolated from the furnace chamber and accurate to 0.1 g. The balance shall be capable of weighing a 3500-g specimen in addition to the specimen baskets. A data collection system will be included so that the mass can be automatically determined and displayed during the test. The furnace shall have a built-in computer program to calculate the change in mass of the specimen baskets and provide for the input of a correction factor for aggregate loss. The furnace shall provide a printed ticket with the initial specimen mass, specimen mass loss, temperature compensation, correction factor, corrected asphalt binder content (percent), test time, and test temperature. The furnace shall provide an audible alarm and indicator light when the specimen mass loss does not exceed 0.01 percent of the total specimen mass for 3 consecutive minutes. The furnace shall also allow the operator to change the ending mass loss percentage to 0.02 percent.

5.2. *Specimen Basket Assembly*—consisting of specimen basket(s), catch pan, and an assembly guard to secure the specimen basket(s) to the catch pan.

5.2.1. *Specimen Basket(s)*—of appropriate size that allows the specimens to be thinly spread and allows air to flow through and around the specimen particles. Sets with two or more baskets shall be nested. The specimen shall be completely enclosed with screen mesh, perforated stainless steel plate, or other suitable material.

Note 1—Screen mesh or other suitable material with maximum and minimum openings of 2.36 mm (No. 8) and 0.600 mm (No. 30), respectively, has been found to perform well.

5.2.2. *Catch Pan*—of sufficient size to hold the specimen basket(s) so that aggregate particles and melting asphalt binder falling through the screen are caught.

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5.3. *Oven*—Capable of maintaining 110 ± 5°C (230 ± 9°F).

5.4. *Balance*—of sufficient capacity and conforming to the requirements of M 231, Class G 2.

5.5. *Safety Equipment*—safety glasses or face shield, dust mask, high temperature gloves, long-sleeved jacket, a heat-resistant surface capable of withstanding 650°C (1202°F), and a protective cage capable of surrounding the specimen baskets during the cooling period.

5.6. *Miscellaneous Equipment*—a pan larger than the specimen basket(s) for transferring the specimen after ignition, spatulas, bowls, and wire brushes.

6. SAMPLING

6.1. Obtain samples of freshly produced HMA in accordance with T 168.

6.2. The specimen shall be the end result of reducing a larger sample in accordance with R 47.

6.3. If the mixture is not sufficiently soft to separate with a spatula or trowel, place it in a large, flat pan in an oven at 110 ± 5°C (230 ± 9°F) until it is workable. Do not leave the specimen in the oven for an extended period of time. Excessive heating may cause detrimental effects such as asphalt drain-down or oxidation.

6.4. The size of the test specimen shall be governed by the nominal-maximum aggregate size of the HMA and shall conform to the mass requirement shown in Table 1. When the mass of the specimen exceeds the capacity of the equipment used, the specimen may be divided into suitable increments, tested, and the results appropriately combined for calculation of the asphalt binder content (using a weighted average). Specimen sizes shall not be more than 500 g greater than the minimum recommended specimen mass.

Note 2—Large specimens of fine mixes tend to result in incomplete ignition of asphalt binder.

Table 1—Mass Requirements

Nominal-Maximum Aggregate Size,[a] mm	Sieve Size	Min 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 1/2 in.	4000

[a] Nominal-maximum aggregate size—one size larger than the first sieve to retain more than 10 percent.

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TEST METHOD A—INTERNAL BALANCE

7. TEST PROCEDURES

7.1. *Test Initiation*:

7.1.1. For the convection-type furnace, preheat the ignition furnace to 538°C (1000°F) or to the temperature determined by the correction factor process in the Annex. Manually record the furnace temperature (set point) prior to the initiation of the test if the furnace does not record automatically.

7.1.2. For the direct IR irradiation-type furnace, use the same burn profile as used during the correction factor determination.

7.2. Oven dry the HMA specimen to a constant mass at a temperature of 110 ± 5°C (230 ± 9°F), or determine the moisture content of a companion specimen according to T 329.

7.3. Enter into the ignition furnace, or manually record, the asphalt binder correction factor for the specific mix to be tested, as determined in the Annex.

7.4. Determine and record the mass of the specimen basket assembly to the nearest 0.1 g.

7.5. Prepare the specimen as described in Section 6. Place the specimen basket(s) in the catch pan. Evenly distribute the specimen in the basket(s), taking care to keep the material away from the edges of the basket. Use a spatula or trowel to level the specimen.

7.6. Determine and record the total mass of the specimen and specimen basket assembly at room temperature to the nearest 0.1 g. Calculate and record the initial mass of the specimen M_i (total mass minus the mass of the specimen basket assembly).

7.7. Input the initial mass of the specimen, M_i, in whole grams into the ignition furnace controller. Verify that the correct mass has been entered.

7.8. Open the chamber door, and place the specimen basket assembly in the furnace, carefully positioning the specimen basket assembly so it is not in contact with the furnace walls. Close the chamber door, and verify that the specimen mass (including the basket assembly) displayed on the furnace scale equals the total mass recorded in Section 7.6 within ±5 g. Differences greater than 5 g or failure of the furnace scale to stabilize may indicate that the specimen basket assembly is contacting the furnace wall.

Note 3—Due to the extreme heat of the furnace, the operator should wear safety equipment—high temperature gloves, face shield, fire-retardant shop coat—when opening the door to load or unload the specimen.

7.9. Initiate the test by pressing the start/stop button. This operation will lock the specimen chamber and start the combustion blower.

Note 4—The furnace temperature will drop below the set point when the door is opened but will recover with the door closed and when ignition occurs. Specimen ignition typically increases the temperature well above the set point, depending on the specimen size and asphalt binder content.

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7.10. Allow the test to continue until the stable light and audible stable indicator indicate the test is complete (the change in mass does not exceed 0.01 percent for 3 consecutive minutes). Press the start/stop button. This operation will unlock the specimen chamber and cause the printer to print out the test results.

Note 5—An ending mass loss percentage of 0.02 may be substituted when aggregate exhibits an excessive amount of loss during ignition testing. The precision and bias statement was developed using 0.01 percent. Both precision and accuracy may be adversely affected by using 0.02 percent.

7.11. Open the chamber door, remove the specimen basket assembly, and place it on a cooling plate or block. Place the protective cage over the specimen basket assembly, and allow it to cool to room temperature (approximately 30 min).

7.12. Determine and record the total mass of the specimen and specimen basket assembly after ignition to the nearest 0.1 g. Calculate and record the final mass of the specimen, M_f (total mass minus the mass of the specimen basket assembly).

7.13. Use the corrected asphalt binder content (percent) from the printed ticket. If this value is not corrected, subtract the asphalt binder correction factor. If a moisture content has been determined per T 329, subtract the percent moisture from the asphalt binder content on the printed ticket, and report the resultant value as the corrected asphalt binder content (P_b).

Note 6—Asphalt binder content can also be calculated using Equation 1 from Method B (Section 8.16).

TEST METHOD B—EXTERNAL BALANCE

8. TEST PROCEDURES

8.1. Preheat the ignition furnace to 538°C (1000°F) or the temperature determined by the correction factor process in the Annex.

8.2. Oven dry the HMA specimen to a constant mass at a temperature of 110 ± 5°C (230 ± 9°F), or determine the moisture content of a companion specimen according to T 329.

8.3. Record the asphalt binder correction factor for the specific mix to be tested, as determined by the correction factor process in the Annex.

8.4. Determine and record the mass of the specimen basket assembly to the nearest 0.1 g.

8.5. Prepare the specimen as described in Section 6. Place the specimen baskets in the catch pan. Evenly distribute the specimen in the basket(s), taking care to keep the material away from the edges of the basket. Use a spatula or trowel to level the specimen.

8.6. Determine and record the total mass of the specimen basket assembly at room temperature to the nearest 0.1 g. Calculate and record the initial mass of the specimen, M_i (total mass minus the mass of the specimen basket assembly).

8.7. Open the chamber door and place the specimen basket assembly in the furnace. Burn the HMA specimen in the furnace for at least 45 min.

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Note 7—The appropriate time for the initial burn of an HMA specimen is dependent on the specimen size. For large specimens, the time could be significantly longer than 45 min. See the manufacturer's manual for guidelines.

8.8. Open the chamber door, remove the specimen basket assembly, and place it on a cooling plate or block. Place the protective cage over the specimen basket assembly, and allow it to cool to room temperature (approximately 30 min).

8.9. Determine and record the total mass of the specimen and specimen basket assembly after cooling to the nearest 0.1 g.

8.10. Place the specimen and specimen basket assembly back into the furnace.

8.11. Burn the specimen for at least 15 min after the furnace reaches the set point temperature.

8.12. Open the chamber door, remove the specimen and specimen basket assembly, and place it on a cooling plate or block. Place the protective cage over the specimen basket assembly, and allow it to cool to approximately room temperature (approximately 30 min).

8.13. Weigh and record the total mass of the specimen and specimen basket assembly after cooling to the nearest 0.1 g.

8.14. Repeat Sections 8.10 through 8.13 until the change in measured mass of the specimen after ignition does not exceed 0.01 percent of the initial specimen mass, M_i.

Note 8—An ending mass loss percentage of 0.02 may be substituted when aggregate exhibits an excessive amount of loss during ignition testing. The precision and bias statement was developed using 0.01 percent. Both precision and accuracy may be adversely affected by using 0.02 percent. After the time required to obtain the specified mass loss has been established for each mixture, repeated mass determinations may not be necessary.

8.15. Calculate and record the final mass of the specimen, M (total mass minus the mass of the specimen basket assembly).

8.16. Calculate the asphalt binder content of the specimen as follows:

$$P_b.\% = \left[\frac{\left(M_i - M_f\right)}{M_i} \times 100\right] - C_F - MC \qquad (1)$$

where:

P_b = the measured (corrected) asphalt binder content, percent;

M_i = the total mass of the HMA specimen prior to ignition, g;

M_f = the total mass of aggregate remaining after the ignition, g;

C_F = the correction factor, percent by mass of HMA specimen; and

MC = the moisture content of companion HMA specimen, percent, as determined by T 329. (If the specimen was oven dried prior to initiating the procedure, $MC = 0$.)

9. GRADATION

9.1. Allow the contents of the specimen baskets to cool to room temperature prior to performing the gradation analysis. Empty the contents of the baskets into a flat pan, being careful to capture all

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material. Use a small wire sieve brush to ensure that any residual fines are removed from the baskets and catch pan.

9.2. Perform the gradation analysis according to T 30.

10. REPORT

10.1. *The report shall include the following*:

10.1.1. Test method (A or B);

10.1.2. Corrected asphalt binder content;

10.1.3. Correction factor;

10.1.4. Temperature compensation factor (if applicable);

10.1.5. Specimen mass;

10.1.6. Moisture content (if determined, per T 329); and

10.1.7. Test temperature.

Note 9—If Method A is performed, attach the original printed ticket to the report.

11. PRECISION AND BIAS

11.1. *Precision*—Criteria for judging the acceptability of ignition burn results for asphalt content obtained by Method A or Method B are given in Table 2.

11.1.1. *Single-Operator Precision*—The figures in Column 2 of Table 2 are the standard deviations that have been found to be appropriate for the conditions of test described in Column 1. Two results obtained in the same laboratory, by the same operator using the same equipment, in the shortest practical period of time, should not be considered suspect unless the difference in the two results exceeds the values given in Table 2, Column 3.

11.1.2. *Multilaboratory Precision*—The figures in Column 2 of Table 2 are the standard deviations that have been found to be appropriate for the conditions of test described in Column 1. Two results submitted by two different operators testing the same material in different laboratories shall not be considered suspect unless the difference in the two results exceeds the values given in Table 2, Column 3.

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Table 2—Precision Estimates

Condition	Standard Deviation, (1s)[a]	Acceptable Range of Two Test Results, (d2s)[a]
Single-Operator Precision		
Asphalt content (%)	0.069	0.196
Multilaboratory Precision		
Asphalt content (%)	0.117	0.330

[a] These values represent the 1s and d2s limits described in ASTM C 670

Note 10—The precision estimates given in Table 2 are based on the analysis of test results from three pairs of AMRL proficiency samples. The data analyzed consisted of results from 353 to 461 laboratories for each of the three pairs of samples. The analysis included two binder grades: PG 52-34 and PG 64-22. Average results for asphalt content ranged from 4.049 to 5.098 percent. The details of this analysis are in NCHRP Final Report, NCHRP Project No. 9-26, Phase 3.

Note 11—The precision estimates are based on four aggregate types, four replicates, and 12 laboratories participating with no laboratory results deleted as outlying observations. All four aggregates were tested in surface mixes and had relatively low absorption values.

11.2. *Bias*—Any biases inherent to the ignition oven process used for Test Methods A and B, when testing for asphalt content and aggregate gradation, are accounted for by the determination and application of appropriate correction factors.

ANNEX

(Mandatory Information)

CORRECTION FACTORS

A1. ASPHALT BINDER AND AGGREGATE

A1.1. Asphalt binder content results may be affected by the type of aggregate in the mixture and the ignition furnace. Therefore, asphalt binder and aggregate correction factors must be established by testing a set of correction specimens for each job mix formula (JMF) mix design. Correction factor(s) must be determined before any acceptance testing is completed and repeated each time a change in the mix ingredients or design occurs. Any changes greater than 5 percent in stockpiled aggregate proportions should require a new correction factor. Historical data or scientific studies may be used to determine the correction factor(s) in lieu of using this testing procedure if the testing agency provides reference to the studies/data.

A1.1.1. *Asphalt binder correction factor*—Certain aggregate types may result in unusually high correction factors (greater than 1.0 percent). Such mixes should be corrected and tested at a lower temperature, as described below. Each ignition furnace will have its own unique asphalt binder correction factor determined in the location where testing will be performed.

A1.1.2. *Aggregate correction factor*—Due to potential aggregate breakdown during the ignition process, an aggregate correction factor will be determined for each ignition furnace in the location where testing will be performed when the following conditions occur: aggregates that have a proven history of excessive breakdown or aggregates from an unknown source.

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A2. CORRECTION FACTOR PROCEDURE

A2.1. Obtain samples of aggregate in accordance with T 2.

A2.2. Obtain samples of asphalt binder in accordance with T 40.

Note A1—Include other additives that may be required by the JMF.

A2.3. Prepare an initial, or "butter mix" at the design asphalt binder content. Mix and discard the butter mix prior to preparing any of the correction specimens to ensure an accurate asphalt binder content.

A2.4. Prepare two correction specimens at the JMF design asphalt binder content and gradation. Aggregate used for correction specimens shall be sampled from the material designated for use in production. An additional "blank" (aggregate only) specimen shall be batched at the JMF gradation. Determine an aggregate gradation in accordance with T 30 on the "blank" specimen.

A2.5. Place the freshly mixed specimens directly into the specimen basket assembly. If specimens are allowed to cool prior to placement in the specimen basket assembly, the specimens must be dried to constant mass at a temperature of 110 ± 5°C (230 ± 9°F). Do not preheat the specimen basket assembly.

A2.6. Test the specimens in accordance with Method A or Method B of the procedure.

A2.7. Once both of the correction specimens have been burned, determine the asphalt binder content for each specimen by calculation or from the printed oven tickets, if available.

A2.8. If the difference between the asphalt binder contents of the two specimens exceeds 0.15 percent, repeat Section A2.3 through A2.7 with two more specimens and, from the four results, discard the high and low result. Determine the correction factor from the two original or remaining results as appropriate. Calculate the difference between the actual and measured asphalt binder contents for each specimen. The asphalt binder correction factor, C_F, is the average of the differences expressed as a percentage by mass of the HMA.

A2.8.1. If the asphalt binder correction factor exceeds 1.0 percent, the test temperature should be lowered to 482 ± 5°C (900 ± 8°F) for convection type furnace. If there is no improvement in the correction factor, it is permissible to use the higher temperature.

Note A2—The temperature for determining the asphalt binder content of HMA specimens by this procedure shall be the same temperature determined for the correction specimens.

A2.8.2. For the direct IR irradiation-type furnaces, the DEFAULT burn profile should be used for most materials. The operator may select burn-profile OPTION 1 or OPTION 2 to optimize the burn cycle. Option 1 is designed for aggregate that require a large aggregate correction factor (greater than 1 percent)—typically very soft aggregate (such as dolomite). Option 2 is designed for samples that may not burn completely using the DEFAULT burn profile. The burn profile for testing HMA samples shall be the same burn profile selected for correction samples.

A2.9. Perform a gradation analysis on the residual aggregate in accordance with T 30, if required. The results will be utilized in developing an aggregate correction factor and should be calculated and reported to the nearest 0.1 percent.

A2.9.1. From the gradation results, subtract the percent passing for each sieve for each specimen from the percent passing each sieve of the "blank" specimen gradation results from Section A2.4.

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A2.9.2. Determine the average difference for the two values. If the difference for any single sieve exceeds the allowable difference for that sieve as listed in Table A2.1, then aggregate gradation correction factors (equal to the resultant average differences) for all sieves shall be applied to all acceptance gradation test results determined by T 30, prior to final rounding and reporting. If the 0.075-mm (No. 200) sieve is the only sieve outside the limits in Table A2.1, apply the aggregate correction factor to only the 0.075-mm (No. 200) sieve.

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

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Standard Method of Test for

Viscosity Determination of Asphalt Binder Using Rotational Viscometer

AASHTO Designation: T 316-11

1. SCOPE

1.1. This test method outlines the procedure for measuring the viscosity of asphalt binders at elevated temperature from 60 to over 200°C using a Rotational Viscometer apparatus as specified by M 320 and R 29.

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

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 320, Performance-Graded Asphalt Binder
- R 29, Grading or Verifying the Performance Grade (PG) of an Asphalt Binder
- T 40, Sampling Asphalt Materials

2.2. *ASTM Standards*:

- C 670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- E 1, Standard Specification for ASTM Liquid-in-Glass Thermometers

3. TERMINOLOGY

3.1. *viscosity*—the ratio between the applied shear stress and the rate of shear is called the coefficient of viscosity. This coefficient is a measure of the resistance to flow of the liquid. It is commonly called the viscosity. The SI unit of viscosity is the Pascal second (Pa·s).

4. SUMMARY OF METHOD

4.1. This test method can be used to measure the viscosity of asphalt at application temperatures. The torque required to maintain a constant rotational speed of a cylindrical spindle while submerged in an asphalt sample at a constant temperature is used to measure the relative resistance to rotation. The torque and speed are used to determine the viscosity of the binder in Pascal seconds.

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5. SIGNIFICANCE AND USE

5.1. This test method can be used to measure the apparent viscosity of asphalt at application temperatures.

5.2. The measured viscosity at elevated temperatures can be used to determine whether the asphalt binder can be handled and pumped at the refinery, terminal, or hot mix plant facility. Measured viscosity from this procedure can be used to develop temperature viscosity charts for estimating mixing and compaction temperatures for use in hot mix asphalt mix design.

6. APPARATUS

6.1. *Oven*—An oven capable of maintaining any desired temperature setting from room temperature to 260°C to within ±3°C.

6.2. *Thermometers*—Thermometers having a range from 60 to over 200°C and readable to 0.2°C.

6.3. *Balance*—A balance with a capacity of 2000 g readable to 0.1 g for determining the mass of asphalt binder.

6.4. *Cylindrical Spindles* of various sizes for measurement of asphalt binders of different viscosities.

6.5. *Rotational Viscometer* capable of measuring the torque required to rotate the selected spindle at a selected constant speed while submerged in asphalt at constant desired test temperature and should display the viscosity in Pascal seconds automatically.

6.6. *Temperature Controller*—A proportional temperature controller capable of maintaining the specimen temperatures ±1.0°C for test temperatures ranging from 60 to 165°C or greater.

7. MATERIALS

7.1. Solvent (such as Mineral Spirits or Varsol) or a degreasing spray cleaner formulated for cleaning the sample holder, spindles, and accessories.

8. HAZARDS

8.1. Use standard laboratory safety procedures required for handling the hot asphalt binder and required safety procedures when cleaning with solvents or degreasers.

9. PREPARATION OF APPARATUS

9.1. The rotational viscometer must be leveled to function properly. A bubble-type level is normally located on top of the viscometer and is adjusted by using leveling screws located on the base. If the torque controller and thermal chamber are separate units, both should be leveled in accordance with the device manufacturer's instructions.

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10. CALIBRATION AND STANDARDIZATION

10.1. The accuracy of the rotary transducer is checked using a reference fluid (Newtonian fluid) of known viscosity at various temperatures. The reference fluid shall be certified to be Newtonian in behavior over the full range of expected test temperatures and shear rates. The viscosity measured should be within ±2 percent or the rotary transducer requires recalibration.

10.2. The accuracy of the temperature reading of the temperature controller is checked by placing an asphalt sample in the testing chamber and equilibrating to a given temperature. The indicated temperature shall be verified by using a NIST traceable measuring device as defined by ASTM E 1.

11. PREPARATION OF SAMPLES AND TEST SPECIMENS

11.1. *Preparing Test Samples*—Unaged asphalt and modified asphalt binders are obtained according to T 40.

11.1.1. Anneal the asphalt binder from which the specimen is obtained by heating until sufficiently fluid to pour. Annealing prior to testing removes reversible molecular associations (steric hardening) that may occur during normal storage at ambient temperature.

Note 1—Minimum pouring temperature that produces a consistency equivalent to that of SAE 10W30 motor oil (readily pours but not overly fluid) at room temperature are recommended. The specific temperature will depend on the grade of binder and its prior aging history, if any. Temperatures less than 135°C are desirable; however, temperatures above 135°C may be required for some modified asphalt binders or heavily aged binders.

12. PROCEDURE

12.1. Read and understand the information in the rotational viscometer manufacturer's operating manual before proceeding.

12.2. Turn on the rotational viscometer and proportional temperature controller unit.

12.3. Preheat the sample holder with the sample chamber and the selected cylindrical spindle according to the manufacturer's recommendation.

12.4. Set the proportional temperature controller to desired test temperature.

12.5. Heat the required amount of asphalt binder as recommended by the manufacturer for testing according to Section 11.1.1.

12.6. When the proportional temperature controller reads the desired test temperature, remove the sample holder, and add the required amount of asphalt into the sample chamber.

12.7. Insert the sample chamber into the proportional temperature controller unit.

12.8. Insert a preheated spindle and attach it to the viscometer using the necessary coupling. Gently lower the spindle into the asphalt so that asphalt covers the upper conical portion of the spindle. This procedure may vary based on the manufacturer's recommendations.

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12.9. Bring the asphalt sample to the desired temperature within approximately 30 minutes. Set the viscometer speed at 20 rpm and set the display to read the viscosity in Pascal seconds (Pa·s). This operation may be done manually or by using a software program.

12.10. Allow the asphalt sample to equilibrate at the desired test temperature for a minimum of 10 minutes. Begin the spindle rotation during the 10-minute temperature equilibration period. Allow the readings to stabilize before recording any viscosity measurements. If the observed torque is out of range for the selected spindle and speed, change the spindle and or speed based on the manufacturer's recommendations for the anticipated viscosity. Restart the test with a new sample.

12.11. Start the test after the asphalt sample has reached the specified temperature and equilibrated and the viscosity readings have stabilized, as required in Sections 12.9 and 12.10.

12.12. Measure the viscosity at one-minute intervals for a total of three minutes.

12.13. Follow the procedure in Sections 12.1 to 12.12 for other temperatures.

13. CALCULATION OF RESULTS

13.1. The viscosity is reported as the average of three readings. If the digital output of the rotational viscometer viscosity is in units of centipoise (cP), the following factor is used to convert to Pascal-seconds:

$$10\ \text{P} = 1\ \text{Pa} \times \text{s} \quad (1)$$

$$1\ \text{cP} = 1\ \text{mPa} \times \text{s} \quad (2)$$

Multiply viscosity in centipoise by 0.001 to obtain the viscosity in Pa·s.

14. REPORT

14.1. *Report the following information*:

14.1.1. Report the date and time of the test;

14.1.2. Report the test temperature to the nearest 1°C;

14.1.3. Report the speed in rpm;

14.1.4. Report the size of the spindle used;

14.1.5. Report the torque in percent; and

14.1.6. Report the average viscosity in Pa·s.

15. PRECISION AND BIAS

15.1. *Precision*—Criteria for judging the acceptability of viscosity results obtained by this method are given in Table 1.

15.1.1. *Single-Operator Precision (Repeatability)*—The figures in Column 2 of Table 1 are the coefficients of variation that have been found to be appropriate for the conditions of test described

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in Column 1. Two results obtained in the same laboratory, by the same operator using the same equipment, in the shortest practical period of time, should not be considered suspect unless the difference in the two results, expressed as a percent of their mean, exceeds the values given in Table 1, Column 3.

15.1.2. *Multilaboratory Precision (Reproducibility)*—The figures in Column 2 of Table 1 are the coefficients of variation that have been found to be appropriate for the conditions of test described in Column 1. Two results submitted by two different operators testing the same material in different laboratories shall not be considered suspect unless the difference in the two results, expressed as a percent of their mean, exceeds the values given in Table 1, Column 3.

Table 1—Precision Estimates

Condition	Coefficient of Variation (1s%)[a]	Acceptable Range of Two Test Results (d2s%)[a]
Single-Operator Precision:		
Average Viscosity (Pa·s)	1.2	3.5
Multilaboratory Precision:		
Average Viscosity (Pa·s)	4.3	12.1

[a] These values represent the 1s% and d2s% limits described in ASTM Practice C 670.

Note 2—The precision estimates given in Table 1 are based on the analysis of test results from eight pairs of AMRL proficiency samples. The data analyzed consisted of results from 142 to 202 laboratories for each of the eight pairs of samples. The analysis included five binder grades: PG 52-34, PG 64-16, PG 64-22, PG 70-22, and PG 76-22 (SBS modified). Unmodified binder average viscosity results ranged from 0.272 Pa·s to 0.719 Pa·s. The modified binder average viscosity results ranged from 1.621 Pa·s to 1.638 Pa·s. The details of this analysis are in the final report for NCHRP Project No. 9-26, Phase 3.

Note 3—As an example, two tests conducted on the same material yield viscosity results of 0.500 Pa·s and 0.510 Pa·s, respectively. The average of these two measurements is 0.505 Pa·s. The acceptable range of results is then 3.5 percent of 0.505 Pa·s or 0.018 Pa·s. As the difference between 0.500 Pa·s and 0.510 Pa·s is less than 0.018 Pa·s, the results are within the acceptable range.

15.2. *Bias*—No information can be presented on the bias of the procedure because no material having an accepted reference value is available.

16. KEYWORDS

16.1. Asphalt binder; viscosity.

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Designation: D4867/D4867M – 09

Standard Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures[1]

This standard is issued under the fixed designation D4867/D4867M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers procedures for preparing and testing asphalt concrete specimens for the purpose of measuring the effect of water on the tensile strength of the paving mixture. This test method is applicable to dense mixtures such as those appearing in the Table for Composition of Bituminous Paving Mixtures in Specification D3515. This test method can be used to evaluate the effect of moisture with or without antistripping additives including liquids and pulverulent solids such as hydrated lime or portland cement.

1.2 The values stated in either SI units or inch-pound units in parentheses shall be regarded separately as standard. The values in each system may not be exact equivalents; therefore, each system must be used independently of the other, without combining values in any way.

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D979 Practice for Sampling Bituminous Paving Mixtures
D1074 Test Method for Compressive Strength of Bituminous Mixtures
D1561 Practice for Preparation of Bituminous Mixture Test Specimens by Means of California Kneading Compactor
D2041 Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures
D2726 Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures
D3203 Test Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures
D3387 Test Method for Compaction and Shear Properties of Bituminous Mixtures by Means of the U.S. Corps of Engineers Gyratory Testing Machine (GTM)
D3496 Practice for Preparation of Bituminous Mixture Specimens for Dynamic Modulus Testing
D3515 Specification for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures[3]
D3549 Test Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens
D3665 Practice for Random Sampling of Construction Materials
D4013 Practice for Preparation of Test Specimens of Bituminous Mixtures by Means of Gyratory Shear Compactor
D4123 Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures[3]
D6926 Practice for Preparation of Bituminous Specimens Using Marshall Apparatus

3. Summary of Test Method

3.1 *Potential for Moisture Damage*—The degree of susceptibility to moisture damage is determined by preparing a set of laboratory-compacted specimens conforming to the job-mix formula without an additive. The specimens are compacted to a void content corresponding to void levels expected in the field, usually in the 6 to 8 % range. The set is divided into two subsets of approximately equal void content. One subset is maintained dry while the other subset is partially saturated with water and moisture conditioned. The tensile strength of each subset is determined by the tensile splitting test. The potential for moisture damage is indicated by the ratio of the tensile strength of the wet subset to that of the dry subset.

3.2 *Additive Effect*—The effect of an antistripping additive is determined on a set of specimens containing an additive prepared and tested as described in 3.1. The effect of an additive dosage may be estimated by repeating the tests on sets with different additive dosages.

3.3 *Plant-Produced Mixtures*—The potential for moisture damage or the effectiveness of an additive in a plant-produced mixture is determined on specimens that are laboratory compacted to expected field-level void content, divided into wet and dry subsets, and evaluated as described in 3.2.

[1] This test method is under the jurisdiction of ASTM Committee D04 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.22 on Effect of Water and Other Elements on Bituminous Coated Aggregates.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Withdrawn. The last approved version of this historical standard is referenced on www.astm.org.

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4. Significance and Use

4.1 This test method can be used to test asphalt concrete mixtures in conjunction with mixture design testing to determine the potential for moisture damage, to determine whether or not an antistripping additive is effective, and to determine what dosage of an additive is needed to maximize the effectiveness. This test method can also be used to test mixtures produced in plants to determine the effectiveness of additives under the conditions imposed in the field.

5. Apparatus

5.1 To prepare and compact the specimens use apparatus from any one of the following: Test Methods D1074, and D3387, Practice D3496, or Practices D1561, D4013, and D6926.

5.2 *Vacuum Pump or Water Aspirator* in accordance with Test Method D2041.

5.3 *Manometer or Vacuum Gage* in accordance with Test Method D2041.

5.4 *Container*, preferably Type F, of Test Method D2041.

5.5 *Balance* in accordance with Test Method D2726.

5.6 *Water Baths* Three:

5.6.1 One waterbath in accordance with Test Method D2726.

5.6.2 One bath capable of maintaining a temperature of 60 ± 1.0°C (140 ± 1.8°F) for 24 h, and

5.6.3 One bath capable of maintaining a temperature of 25 ± 1.0°C (77 ± 1.8°F).

5.7 *Mechanical* or *Hydraulic Testing Machine* capable of maintaining the required strain rate and measuring load with equal or better precision.

5.8 *Loading Strips* in accordance with Test Method D4123.

6. Preparation of Laboratory Test Specimens

6.1 Make at least six specimens for each test, three to be tested dry and three to be tested after partial saturation and moisture conditioning.

6.2 Use specimens 100 mm (4 in.) in diameter and 62.5 mm (2.5 in.) high, in general, but specimens of other dimensions may be used if desired. When using aggregate larger than 25 mm (1 in.), use specimens at least 150 mm (6 in.) in diameter.

NOTE 1—The user is cautioned that the specimen diameter has been determined to influence both the tensile strength and the tensile strength ratio. The tensile strength and the tensile strength ratio values may be different for 150–mm specimens compared to 100–mm specimens.

6.3 Prepare mixtures in batches large enough to make at least 3 specimens or, as an alternative, prepare a batch just large enough for 1 specimen. If theoretical maximum specific gravity is to be determined, use a batch large enough or prepare a separate batch to provide a specimen for this purpose.

6.4 When a liquid antistripping additive is used, heat a sufficient quantity of asphalt cement for one batch to 150 ± 6°C (300 ± 10°F) in a closed 1 L (1-qt) can in an oven. Add the required quantity of additive and immediately mix, for approximately 2 min, with a mechanical stirrer approximately 25 mm (1 in.) from the bottom of the container. Maintain the treated asphalt cement at 150 ± 6°C (300 ± 10°F) in the closed can until it is used. Discard the treated asphalt cement if not used the same day it is prepared, or if allowed to cool so that it requires reheating.

6.5 When using a pulverulent solid antistripping additive , use the addition procedure simulating the procedure expected in the field. Follow the procedure specified in either 6.5.1, 6.5.2, or 6.5.3.

6.5.1 When dry powder is added to dry aggregate, dry, batch, and heat the mineral aggregate to 150 ± 6°C (300 ± 10°F). Add the required quantity of additive to the aggregate, and thoroughly mix the entire mass until a uniform distribution of additive is achieved. Take care to minimize the loss of additive to the atmosphere in the form of dust. After mixing, maintain the treated aggregate at the required mixing temperature until it is used.

6.5.2 When dry powder is added to damp aggregate, batch the damp mineral aggregate, and adjust the moisture content of the combined aggregate to the expected field moisture level. Add the required quantity of additive to the damp aggregate, and thoroughly mix the entire mass until a uniform distribution of additive is achieved. Take care to minimize the loss of additive to the atmosphere in the form of dust. After mixing, dry the treated aggregate, heat to the required mixing temperature, and maintain at that temperature until it is used.

6.5.3 When powder slurry is used, add the required quantity of additive to water using the powder to water ratio expected in the field. Take care to minimize the loss of additive to the atmosphere in the form of dust. To prevent settling, continuously mix the resulting slurry until it is used. Batch the damp mineral aggregate, adjust the moisture content as required in 6.5.2, add the required quantity of slurry, and thoroughly mix the entire mass until a uniform distribution of slurry is achieved. After mixing, dry the treated aggregate, heat to the required mixing temperature, and maintain at that temperature until used.

6.6 Proportion, mix, and compact specimens in accordance with one of the following: Test Methods D1074, D3387, Practice D3496, Practices D1561, D4013, or D6926, and 6.6.1 and 6.6.2.

6.6.1 After mixing, stabilize the mixture temperature of each specimen at the required compaction temperature, in a closed container, in an oven for 1 to 2 h. If preparing a multi-specimen batch, split the batch into single-specimen quantities before placing into the oven.

6.6.2 Compact the specimens to 7 ± 1 % air voids, or a void level expected in the field at the time of construction. This void level can be obtained by adjusting the following: the static load in double-plunger compaction; the number of blows in a marshall hammer compaction; the foot pressure, number of tamps, leveling load, or some combination in kneading compaction; or the number of revolutions in gyratory compaction. Determine the exact procedure by trial for each mixture.

6.6.3 Cool specimens in the mold to room temperature as rapidly as possible in a stream of moving air, extract from molds, then follow the procedure outlined in Section 8 within 24 h.

7. Preparation of Field Specimens

7.1 Select a truck to be sampled in accordance with Practice D3665.

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7.2 Secure a sample from the truck at the plant in accordance with Practice D979.

7.3 Stabilize the mixture temperature to approximately the temperature found in the field when rolling begins. Maintain this temperature in a closed container, in an oven if necessary, for approximately the time lapse between mixing and the start of actual rolling.

7.4 Compact the specimens in accordance with 6.6.2, and cool and extract from the molds in accordance with 6.6.3.

7.5 If specimens are not to be compacted in the field laboratory, place the samples in a sealed container, transport to the laboratory, and reheat to the temperature required in 7.3. Proceed with the steps in 7.4.

NOTE 2—Specimens made from plant-produced mixtures in accordance with Section 7 may yield different results from specimens made from laboratory-produced mixtures of the same job mix made in accordance with Section 6.

8. Procedure

NOTE 3—A data sheet that is convenient for use with this procedure appears in Appendix X1.

8.1 Determine the theoretical maximum specific gravity in accordance with Test Method D2041.

8.2 Determine the specimen height in accordance with Test Method D3549.

8.3 Determine the bulk specific gravity in accordance with Test Method D2726, and express the volume of the specimen in cubic centimeters. The term (*B-C*) in Test Method D2726 is the volume of the specimen in cubic centimeters.

8.4 Calculate the percent air voids in accordance with Test Method D3203, and express the volume of air in cubic centimeters. The volume of air is the volume of the specimen in 8.3 multiplied by the percent air voids.

8.5 Sort the specimens into two subsets so that the average air voids of the two subsets are approximately equal. Store the subset to be tested dry at room temperature.

8.6 Partially saturate the subset to be moisture conditioned with distilled water at room temperature using a vacuum chamber. If it is difficult to reach the minimum degree of saturation required in 8.6.3, the water used to saturate may be heated up to 60°C (140°F).

8.6.1 Partially saturate, to the degree specified in 8.6.3, by applying a partial vacuum such as 70 kPa or 525 mm Hg (20 in. Hg) for a short time such as five min.

NOTE 4—Experiments with partial vacuum at room temperature indicate that the degree of saturation is very sensitive to the magnitude of the vacuum and practically independent of the duration. The level of vacuum needed appears to be different for different mixtures.

8.6.2 Determine the volume of the partially saturated specimen in accordance with Test Method D2726. Determine the volume of the absorbed water by subtracting the air-dry mass of the specimen in 8.3 from the saturated surface-dry mass of the partially saturated specimen.

8.6.3 Determine the degree of saturation by dividing the volume of the absorbed water in 8.6.2 by the volume of air voids in 8.4 and express the result as a percentage. If the volume of water is between 55 and 80 % of the volume of air, proceed to 8.7. If the volume of water is less than 55 %, repeat the procedure beginning with 8.6.1 using a slightly higher partial vacuum. If the volume of water is more than 80 %, the specimen has been damaged and is discarded.

NOTE 5—If the average air voids of the saturated subset is less than 6.5 %, a degree of saturation of at least 70 % is recommended.

8.7 Moisture condition the partially saturated specimens by soaking in distilled water at 60 ± 1.0°C (140 ± 1.8°F) for 24 h.

NOTE 6—If a freeze-thaw conditioning cycle is desired, the following procedure is suggested instead of the procedure in 8.7. Wrap each of the partially saturated specimens tightly with two layers of plastic film using masking tape to hold the wrapping if necessary. Place each wrapped specimen into a leak-proof plastic bag containing approximately 3 mL of distilled water, and seal the bag with a tie or tape. Place the wrapped and bagged specimens into an air bath freezer at −18 ± 2.0°C (−0.4 ± 3.6°F). After at least 15 h in the freezer, remove the specimens and immerse them in a water bath at 60 ± 1.0°C (140 ± 1.8°F) for 24 h. After 3 min of immersion, after specimen surface thaw occurs, remove the bag and wrapping from the specimens.

8.8 Adjust the temperature of the moisture-conditioned subset by soaking in a water bath for 1 h at 25 ± 1°C (77 ± 1.8°F).

8.9 Measure the height of the moisture-conditioned subset by Test Method D3549, and determine volume by Test Method D2726.

8.9.1 Determine the water absorption and the degree of saturation in accordance with 8.6.2 and 8.6.3. A degree of saturation exceeding 80 % is acceptable.

8.9.2 Determine the swell of the partially saturated specimens by dividing the change in specimen volumes in 8.6.2 and 8.3 by the specimen volume in 8.3. Determine the swell of moisture-conditioned specimens by dividing the change in the specimen volume in 8.9 and 8.3 by the specimen volume in 8.3.

8.10 Adjust the temperature of the dry subset by soaking in a water bath for 20 min at 25 ± 1.0°C (77 ± 1.8°F).

8.11 Determine the tensile strength at 25 ± 1.0°C (77 ± 1.8°F) of both subsets.

8.11.1 Place a specimen into the loading apparatus and position the loading strips so that they are parallel and centered on the vertical diametral plane. Apply a diametral load at 50 mm/min (2 in./min) until the maximum load is reached, and record the maximum load.

8.11.2 Continue loading until the specimen fractures. Break the specimen open and visually estimate and record the approximate degree of moisture damage, if any.

8.11.3 Inspect all surfaces, including the failed faces, for evidence of cracked or broken aggregate, that may influence test results, and record observations.

9. Calculation

9.1 Calculate the tensile strength as follows:

$$S_t = 2000\,P\,\pi t D \text{ (kPa)} \quad (1)$$

or

$$S_t = 2P/\pi t D \text{ (psi)}$$

where:

S_t = tensile strength, kPa (psi)
P = maximum load, N (lbf)

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t = specimen height immediately before tensile test, mm (in.), and
D = specimen diameter, mm (in.).

9.2 Calculate the tensile strength ratio as follows:

$$TSR = (S_{tm}/S_{td})100 \quad (2)$$

where:
TSR = tensile strength ratio, %
S_{tm} = average tensile strength of the moisture-conditioned subset, kPa (psi), and
S_{td} = average tensile strength of the dry subset, kPa (psi).

10. Report

10.1 Report the following information:

10.1.1 Number of specimens in each subset,

10.1.2 Average air voids of each subset,

10.1.3 Average degree of saturation after partial saturation and after moisture conditioning,

10.1.4 Average swell after partial saturation and after moisture conditioning,

10.1.5 Tensile strength of each specimen in each subset,

10.1.6 Tensile strength ratio,

10.1.7 Results of visually-estimated moisture damage observed when the specimen fractures, and

10.1.8 Results of observations of fractured or crushed aggregate.

NOTE 7—If the conditioning procedure described in Note 6 is used, that fact should be included in the report.

11. Precision and Bias

11.1 *Precision*—The standard deviations for use with this test method have been determined using laboratory-mixed specimens conditioned in accordance with 8.7. Neither plant-mixed material nor the conditioning in Note 6 has been studied. Nineteen laboratories participated in the precision study by testing five asphalt concrete mixtures, two of which contained a liquid antistripping additive.

11.1.1 *Within-Laboratory Precision*—The single-operator standard deviation of tensile strength for either dry or moisture-conditioned specimens has been found to be 55 kPa (8 psi). The d2s limit for the maximum allowable difference in tensile strength between duplicate specimens of the same mixture tested by the same operator is 159 kPa (23 psi).

11.1.2 *Between-Laboratory Precision*—The multilaboratory standard deviation of the tensile-strength ratio has been found to be 8 %. The d2s limit for the maximum allowable difference in tensile-strength ratio between results of tests performed on samples of the same mixture by two different laboratories is 23 %.

11.2 *Bias*—This test method has an undetermined bias because the value of a tensile-strength ratio can be defined only in terms of the test method.

12. Keywords

12.1 antistripping additives; asphalt concrete paving mixtures; moisture; tensile strength; water

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APPENDIX

(Nonmandatory Information)

X1. MOISTURE DAMAGE LABORATORY DATA SHEET

Project									
Additive					Dosage				
Compaction Method					Effort				
	Date Tested					By			
Sample I.D.									
Diameter, mm (in.)	*D*								
Thickness, mm (in.)	*t*								
Dry mass in air	*A*								
SSD mass	*B*								
Mass in water	*C*								
Volume (*B-C*)	*E*								
Bulk Sp. Gr. (*A/E*)	*F*								
Max Sp. Gr.	*G*								
% AirVoid (100(G-F)/G)	*H*								
Volume AirVoid, HE/100	*I*								
Load, N (lbf)	*P*								
Saturated min. @		kPa or mm Hg (in. Hg)							
SSD Mass	*B'*								
Mass in water	*C'*								
Volume (*B'-C'*)	*E'*								
Vol Abs. water (*B'-A*)	*J'*								
% Saturation (100*J'/I*)									
% Swell (100(*E'-E*)/*E*)									
Conditioned 24 h in 140°F water									
Thickness, mm (in.)	*t'*								
SSD Mass	*B'*								
Mass in water	*C'*								
Volume (*B'-C'*)	*E'*								
Vol Abs. Water (*B'-A*)	*J'*								
% Saturation, (100*J'/I*)									
% Swell, 100(*E'-E*)/*E*									
Load, N (lbf)	*P'*								
Dry Strength, 2000 $P/\pi tD$ ($2P/\pi tD$)	S_{td}								
Wet Strength, 2000 $P'/\pi t'D$ ($2P'/\pi t'D$)	S_{tm}								
TSR, $100S_{tm}/S_{td}$									
Visual Moisture Damage									
Crack/Break Aggregate									

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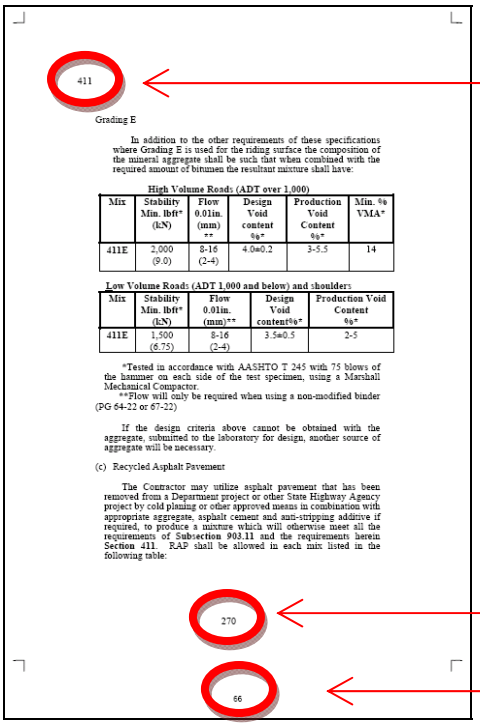

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Grading E

In addition to the other requirements of these specifications where Grading E is used for the riding surface the composition of the mineral aggregate shall be such that when combined with the required amount of bitumen the resultant mixture shall have:

High Volume Roads (ADT over 1,000)

Mix	Stability Min. lbft* (kN)	Flow 0.01in. (mm) **	Design Void content %*	Production Void Content %*	Min. % VMA*
411E	2,000 (9.0)	8-16 (2-4)	4.0±0.2	3-5.5	14

Low Volume Roads (ADT 1,000 and below) and shoulders

Mix	Stability Min. lbft* (kN)	Flow 0.01in. (mm)**	Design Void content%*	Production Void Content %*
411E	1,500 (6.75)	8-16 (2-4)	3.5±0.5	2-5

*Tested in accordance with AASHTO T 245 with 75 blows of the hammer on each side of the test specimen, using a Marshall Mechanical Compactor.

**Flow will only be required when using a non-modified binder (PG 64-22 or 67-22)

If the design criteria above cannot be obtained with the aggregate, submitted to the laboratory for design, another source of aggregate will be necessary.

(c) Recycled Asphalt Pavement

The Contractor may utilize asphalt pavement that has been removed from a Department project or other State Highway Agency project by cold planing or other approved means in combination with appropriate aggregate, asphalt cement and anti-stripping additive if required, to produce a mixture which will otherwise meet all the requirements of Subsection 903.11 and the requirements herein Section 411. RAP shall be allowed in each mix listed in the following table:

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Spec. Section Number

Page Number in Orange 2006 Spec. Book

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SECTION 106-CONTROL OF MATERIALS

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SECTION 106-CONTROL OF MATERIALS

106.01-Quality of Materials. It is the intent of these Specifications that all of the material used in the Work shall conform to all of the quality requirements of the Contract, and that they shall be so controlled and incorporated as to produce completed construction which is fully acceptable under the terms of the Contract.

Where reference is made in any of the contract documents to certain manufacturers' materials or products, it is not the intent to preclude the use of others, but rather to establish minimum acceptable design standards. The Contractor may substitute material and products of other manufacturers provided they meet the minimum design standards and are approved by the Department.

106.02-Material Information. When the Department has readily available test reports on materials from local sources near the project, copies thereof will be furnished to the Contractor, covering each source concerning which specific request is made. In furnishing such reports, the Department acts as an agent of the Contractor and will not be responsible to him if the materials should fail to conform to the test reports either as to quality or quantity.

106.03-Local Material Sources. If the Contractor desires preliminary tests of local materials, he shall deliver samples of the materials, prepaid, to the Laboratory. Tests will be made on such samples, up to a reasonable number, and in such time as the work load in the Laboratory may permit. It must be understood that the development of acceptable test results on preliminary samples will not guarantee acceptance of materials from the same source later.

106.04-Sampling and Testing, or Inspection. All materials will be sampled and tested, or inspected by the Engineer, and unless accepted by the Engineer on the basis of such sampling and testing, or inspection, shall not be incorporated in the Work. Any portions of the Work in which untested or unaccepted materials are used without written permission of the Engineer shall be performed at the Contractor's risk, and may be considered as unacceptable and unauthorized, in which case such portions of the Work will not be paid for. Unless otherwise designated, sampling and testing or inspection will be conducted in accordance with the most recently published methods of AASHTO or ASTM which were current on the date of the Advertisement. Whenever reference is made to other Specifications such as Federal Specifications, Specifications of the AASHTO or to the ASTM Specifications, it shall be understood that the Specification, whether tentative, standard, or interim, current at the date of Advertisement shall apply. All sieves used in testing shall conform to AASHTO M 92. The Contractor shall furnish all materials for samples at no cost to the Department. Sampling and testing, or inspection, will be performed at the expense of the Department unless otherwise specified herein, and only by qualified representatives. All materials which the Department does not elect to sample and test or inspect at the source, will be sampled for testing,

or inspected, after delivery to the site of the Work or to the batching plant at which further processing will be performed. The Contractor shall furnish, or have furnished, all facilities for, and all reasonable assistance in, the securing and transportation of samples, and the movement of materials being inspected.

The sampling and testing frequencies for the acceptance, quality control, independent assurance, verification, or certification for materials and products shall be in accordance with Departmental procedures.

The Engineer may accept certain materials or assemblies based on Certificate of Compliance stating that such materials or assemblies fully comply with the requirements of the Contract. The certificate shall be signed by the manufacturer or his authorized representative. A Certificate of Compliance in which the lot is clearly identified must accompany each lot of such materials or assemblies delivered to the work. All certification submittals must be accompanied with the necessary paperwork as specified in Departmental Procedures.

A Certificate of Compliance for a non-bid item, not permanently incorporated in the work, but that must meet a designated specification, shall be furnished the Engineer upon delivery of the material to the project and prior to its being used.

Materials or assemblies accepted on the basis of Certificate of Compliance may be sampled and tested at any time and if found not in conformity with contract requirements will be subject to rejection.

106.05-Source or Plant Inspection. The responsibility for securing satisfactory material rests entirely with the Contractor. However, if the volume of any given material, the progress of construction, and other considerations of interest to the Department so justify, the Department may undertake the inspection of materials at the source of supply. Such inspection will be undertaken only when the Engineer is assured of the fullest cooperation and assistance of the Contractor and of the material producer involved. This includes copies as required of all orders, shipping information, and other pertinent papers.

The representatives of the Department shall have free and safe entry at all times to such parts of the plant as concern the manufacture and production of material for the project. When the said representatives are in or about the premises referred to above, in the course of their employment, they shall be deemed conclusively to be invitant of the Contractor. If the Contractor is not the owner of the place where fabrication, preparation, or manufacture are in progress, the owner thereof shall be deemed to be the agent of the Contractor, with respect to the obligation assumed hereunder.

106.06-Field Laboratory. The Contractor shall furnish Type A or Type B laboratory(s) or both, as required to be used exclusively for testing purposes. Suitable field laboratories or inspection offices shall also be required at batch plants and sources or plants at which off-site inspection is provided by the Department under **Subsection 106.05**. The laboratory(s) shall be located as directed by the Engineer. The building(s) shall be installed, equipped and ready for use prior to the time the Contractor's operations are such as to require field testing. When a concrete batch plant

is located near a Type B Laboratory used for testing at an asphalt plant, joint use may be approved by the Engineer provided there is ample time and equipment to perform all necessary testing for both operations.

All contractor and producer laboratories must be inspected and qualified in accordance with TDOT procedures before any work can be done.

Type A

A Type A Laboratory shall be a building, room or dedicated area having at least 120 s.f.(11 m^2) of floor area with a minimum width of 8 ft.(2.4m) and a minimum height of 7 ft.(2.1 m). It shall be a building or a portion of a building that is floored, roofed, sealed inside, weather tight and furnished with electricity. It shall be equipped with adequate work benches, cabinets and drawers. It shall be provided with suitable heat and air conditioning and shall be equipped with a gas or electric stove with four burners for drying materials. The laboratory shall be provided with lights and electrical outlets and shall have adequate ventilation for the test being performed.

When the determination of aggregate gradation is required, the following equipment shall be required:

1. Scales of appropriate capacity and design to weigh the required samples. Scales are to be sensitive to within 0.2 per cent of the sample to be weighed. Standard weights shall be available for scale calibration.
2. Screens of appropriate size and mesh to separate the samples into the required series of sizes. Woven wire cloth shall conform to AASHTO M 92. Screens for running gradations of coarse aggregates shall have a minimum area of 2.33 s.f.(0.22 m^2).
3. A mechanical shaker suitable for running both coarse and fine aggregate shall be furnished. The mechanical shaker shall be approved by the Engineer.
4. Facilities, to perform wash tests (AASHTO T 11) which include an adequate, suitable water supply.

Type B

In addition to meeting all of the requirements for a Type A Laboratory, a Type B Laboratory shall be equipped with the following:

1. Laboratory shall have a minimum of 300 s.f.(28 m^2).
2. Laboratory type oven capable of maintaining a temperature of 230° F ± 9° F(110° C ± 5° C).
3. Two vacuum extractors, each having a minimum bowl capacity of 100 ozt (3,000 grams) meeting the requirements of ASTM D 2172, or 1 vacuum extractor and 1 ignition furnace meeting the requirements of AASHTO T 308. It shall be the Contractors responsibility to supply an adequate amount of an approved solvent from the Department's Qualified Products List and to

provide for storage and disposal of the waste solvent in accordance with the regulations promulgated under the Tennessee Hazardous Waste Management Act.

To insure adequate ventilation, the extractor and drying equipment shall be housed in an enclosed hood. The hood shall be equipped with an exhaust fan vented to the outside and mounted at the appropriate location in order to remove the vapors of the solvent. Where the extractor is installed outside the laboratory, only the drying equipment shall be vented as outlined above.

4. Apparatus meeting the requirements of AASHTO T 166, Section 3.1 and 3.2 for determining the bulk specific gravity of a compacted asphalt mix will be required. When required by the Contract, an apparatus meeting the requirements of AASHTO T 209, Section 3.1 through 3.5 for determining the maximum specific gravity of a asphalt mix will be required.
5. A minimum of 2 suitable thermometers with an approximate temperature range of 50-400° F(10-200° C) shall be required.
6. Furnace capable of performing loss on ignition tests for a minimum 10 ozst (600 grams) sample.
7. When required as specified in **Subsection 407.03**, equipment needed to perform Marshall tests as outlined in **AASHTO T 245**. The compactor shall be a Marshall Mechanical type with rotating mold(s) and slanted foot hammers that produce a modified kneading action.

Unless otherwise indicated in the Contract, Field Laboratories will not be paid for as a separate item but will be considered a responsibility to be assumed by the Contractor in connection with stipulated pay items.

106.07-Notice of Source or Arrival of Materials. The Contractor shall purchase all materials sufficiently in advance of need to permit the Engineer to provide for sampling and testing, or inspection. He shall furnish the Department, in writing, the name and location of suppliers that will furnish materials for the project. In case of materials concerning which the Department does not elect to perform sampling and testing, or inspection at the source, the Contractor shall advise the Engineer in writing within twenty-four hours after the arrival on the site of the Work of deliveries of material requiring sampling for testing, or inspection.

106.08-Handling and Storage of Materials. All materials shall be transported in tight, clean vehicles and shall not be subjected to contamination, segregation or other damage either in route to the job site or the batching plant or when moved from point to point at later stages.

Materials shall be stored so as to insure the preservation of their quality and fitness for use. When considered necessary, they shall be stored in weatherproof buildings, placed on wooden platforms, or other hard, clean surfaces and not on the ground, and shall be covered when directed. Stored materials shall be located so as to facilitate prompt inspection. Private property shall not be used for storage purposes without written permission of the owner or lessee. Use of portions of the rights-of-way for storage of

materials or erection of batching plants, requires specific approval of the Engineer.

106.09-Resampling and Testing, or Reinspection. At the option of the Engineer, all materials are subject to resampling and testing, or reinspection at any time after delivery to the site of the Work, or to any batching plant. Such materials are subject to rejection if found unacceptable under these Specifications.

106.10-Defective Material. All materials found to be unacceptable for any reason shall not be delivered to the site if rejected elsewhere, or shall be removed from the site or processing batch plant if rejected there.

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SECTION 307-BITUMINOUS PLANT MIX BASE (HOT MIX)

307.01-Description. This work shall consist of a foundation composed of a hot mixture of aggregate and asphalt prepared in a hot bituminous mixing plant. It shall be constructed in one or more layers, on a prepared subgrade, granular sub-base, or base, in accordance with these Specifications and in reasonably close conformity with the lines, grades, thicknesses and typical cross sections shown on the Plans or as directed by the Engineer.

MATERIALS

307.02-Materials. The materials used in this construction shall conform to the requirements of the following Subsection of **Part 9-Materials**.

Materials	Subsection
Asphalt Cement, Grade PG 64-22, 70-22, 76-22, 82-22	**904.01**
Aggregate for Mixture, Grading A, ACRL, AS, B, BM, BM2, C, CS, or CW	**903.06**
Chemical Additive	**918.09(B)**

The specific grading of aggregate to be used will be specified in the Contract or shown on the Plans. Mineral aggregate, bituminous material and the plant mix will be accepted as provided for in **Subsection 407.02**.

307.03-Composition of Mixtures.

(a) General

The bituminous base and/or leveling course shall be composed of aggregate and bituminous materials. The hot plant mixes shall comply with the applicable requirements of **Subsection 407.03**.

The specified mineral aggregate and asphalt cement shall be combined in such proportions as to produce mixtures within the following design composition limits.

Proportions of Total Mixture, Per Cent by Weight

Mixtures	Combined Mineral Aggregate %	Asphalt Cement%
Grading AS and ACRL	96.3-97.7	2.3-3.7*
Grading A	95.8-96.7	3.3-4.2*
Grading B, BM and BM2	93.8-95.8	4.2-6.2*
Grading C and CW	93.8-95.8	4.2-6.2*
Grading CS	92.3-94.7	5.3-7.7*

* If the effective combined specific gravity of the aggregate exceeds 2.80, the above proportions may be adjusted as directed by the Engineer.

In addition, the combination of materials shall be such that when combined with the required amount of bitumen, the resultant mixture shall have:

Mix***	Stability Min. lbf* (kN)	Design void% content *	Production void %* content	Min. % VMA *	Dust-asphalt ratio**
307-B	2,000(9.0)	4.0±0.2	3-5.5	11.5	0.6-1.5
307- BM	2,000(9.0)	4.0±0.2	3-5.5	13.5	0.6-1.5
307-BM-2	2,000(9.0)	4.0±0.2	3-5.5	13.5	0.6-1.5
307-C	2,000(9.0)	4.0±0.2	3-5.5	13.0	0.6-1.5
307-CS	2,000(9.0)	3.0±0.5	1-5	---	---
307-CW	1,500(6.75)	4.0±0.2	3-5	13.0	0.6-1.5

*Tested in accordance with AASHTO T 245 with 75 blows with the hammer on each end of the test specimen, using a Marshall Mechanical Compactor.

**The dust to asphalt ratio is the percent of the total aggregate sample that passes the 200 mesh(75 µm) sieve as determined by AASHTO T 11 divided by the percent asphalt in the total mix.

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

Except that on low volume roads(ADT 1,000 or below) the minimum stability shall be 1,500 lb-ft (6.75 kN) and the VMA and Dust-Asphalt Ratio shall be waived for 307-B, 307-BM, 307-BM2 and 307-C mixes.

If the above design criteria cannot be achieved with the materials proposed for use, other sources of materials shall be required. If the material at the asphalt plant will not combine within the tolerances of the Job Mix Formula, a new design will be required.

(b) Recycled Asphalt Pavement.

The Contractor may utilize asphaltic concrete removed from a Department project or other State Highway Agency project by cold planing or other approved means in combination with appropriate aggregate, asphalt cement and antistripping additive if required, to produce a mixture which will otherwise meet all the requirements of **Subsection 903.06** and (a) above. Or the Contractor shall furnish a

mixture composed of all new materials that will comply with the requirements of **Subsection 903.06** and (a) above. The Contractor shall document, to the satisfaction of the Department, the sources of all stockpiled recyclable material proposed for use in the construction.

The stockpile of processed recycled material must be of uniform quality as documented by asphalt content and gradation tests. In any event, at least 65% of the asphalt cement in the final mix shall be new material. Stockpiled material that becomes contaminated will be subject to rejection by the Engineer.

** Mix Type	%RAP* (Non-processed)	%RAP* (Processed)	Maximum Particle size
307ACRL	0	00	-
307AS	0	00	-
307A	15	20	1 ½ in. (38 mm)
307B	15	30	1 ½in. (38 mm)
307BM	15	30	¾ in. (19 mm)
307BM2	15	30	¾ in. (19 mm)
307C	15	30	3/8 in. (9.5 mm)
307CW	15	30	½ in. (13 mm)
307CS	0	15	5/16 in. (8 mm)

*__RAP__ that has been crushed and screened or otherwise sized such that the maximum recycled material particle size is less than that listed in the table above prior to entering the dryer drum, shall qualify as "Processed". "Non processed" **RAP** shall be similar material that has not been crushed and screened or otherwise sized previous to its use.
**All mixes shall contain at least 65% virgin asphalt.

The Contractor shall obtain a representative sample from the recycled material stockpile and establish a gradation and asphalt cement content as required. The Contractor shall determine the gradation and asphalt content of the recycled material at the beginning of a project and every 2,000 tons(2,000 metric tons) thereafter. The stockpile asphalt cement content for all recycled material shall not vary by more than 0.8%. The stockpile gradation tolerance for all recycled material on each sieve is listed below.

3/8 in. (9.50 mm) sieve and larger..... ± 10%
No. 4(4.75 mm) sieve ..... ± 8%
No. 8(2.36 mm) sieve ..... ± 6%
No. 30(600 µm) sieve ..... ± 5%
No. 200(75 µm) sieve ..... ± 4%

The mixture will be accepted for aggregate gradation and asphalt content based on extractions.

A special design with asphalt content in the range of 5 to 7% shall be required where 307 C Mix is used as a surface on the shoulder.

The Contractor shall be responsible for his own sampling and testing of the planings as well as new materials for bid purposes, and for the submission of the job mix formula in accordance with **Subsection 407.03**. All additives shall be submitted to the Engineer for approval at the same time other materials are submitted for design verification.

If the Department has performed tests on the pavement to be cold planed, the results of all tests will be available at the Materials and Tests Division in Nashville, Tennessee during normal working hours. This information is advisory only and shall not be construed as necessarily complete nor accurate.

Where it is necessary to obtain a sample of the existing pavement for mix design, the Contractor shall mill the existing pavement to the full depth shown on the plans for pavement removal for a length of approximately 300 ft. (100 m) in an area approved by the Engineer. The removed pavement shall be replaced as specified on the plans or directed by the Engineer.

After mixing, the moisture content of the total mix shall be no more than 0.1% as determined by oven drying, and the provisions for lowering the temperature because of boiling or foaming shall not apply.

(c) Anti-Strip Additive - Asphaltic concrete mixtures (Grading A, AS, ACRL, B, BM, BM2, C, CS and CW) shall be checked for stripping by the following methods:

1. The Ten Minute Boil test for dosage rate and the Root-Tunnecliff procedure (ASTM D 4867) for moisture susceptibility.
2. For mixtures not requiring design - the Ten Minute Boil test for dosage rate and moisture susceptibility.

* Root-Tunnecliff procedure (ASTM D 4867) shall not be used with the following mixtures: Grading A, AS, ACRL and B

If moisture susceptibility is indicated, then an approved anti-strip agent shall be mixed with the asphalt cement at the dosage recommended by the respective test and as specified in **Subsection 918.09(B).**

EQUIPMENT

307.04-Equipment. All the equipment necessary for the satisfactory performance of this construction shall be on the project, and approved, before work will be permitted to begin. The equipment shall meet the requirements of **Subsection 407.04** through **407.08** of these Specifications.

If recycled mix is used, the asphalt plant shall be modified as approved by the Engineer to accommodate the asphalt planings which are to be added. If a batch plant is used to produce recycled mix, the aggregate shall

be heated to a temperature that will transfer sufficient heat to the cold planings to produce a mix of uniform temperature within the specified range.

CONSTRUCTION REQUIREMENTS

307.05-General. The construction requirements shall be as prescribed in **Subsection 407.09** and **Subsection 407.11** through **407.17** of these Specifications and the following Subsections.

307.06-Preparation of Subgrade, Sub-base, or Surface. The Plans will indicate whether the plant-mixed base is to be constructed on a treated or untreated subgrade or sub-base, on a granular base, or on an existing surface. The surface upon which the plant mix base is to be placed shall meet the requirements of **Section 205, 207, 302, 303, 304**, or **Section 309**, whichever is applicable. Conditioning of surface, when called for on the Plans, shall be in accordance with the provisions of **Subsection 407.10**. Conditioning existing mineral aggregate base shall be in accordance with the provisions of **Section 310**. Prime coat or tack coat, when specified on the Plans, shall be constructed in accordance with the provisions of **Section 402** or **403**, respectively.

Bituminous plant-mix base mixture shall be placed only upon a surface that is dry, and cleaned of loose particles and other undesirable materials.

307.07-Thickness and Surface Requirement. Thickness shall be controlled during the spreading operation by frequent measurements of the freshly spread mixture to establish relationship between the uncompacted mixture and the completed course. Thickness or spread rate in lbs/yd^2(kgs/m^2) shall be within reasonably close conformity with that specified on the Plans. Each course shall have a thickness after compaction of not more than 4 in. (100 mm), unless otherwise authorized by the Engineer.

The surface of the bases shall meet the requirements specified under **Subsection 407.18** and when tested in accordance with the provisions of that Subsection, the deviation of the surfaces from the testing edge of the straightedge shall not exceed the amounts shown below for the several types of mixtures:

Grading A, ACRL and AS Mixture	1/2 in. (13 mm)
Grading B, BM, BM2, C, CS and CW Mixture	3/8 in. (10 mm)

COMPENSATION

307.08-Method of Measurement. Aggregate and Asphalt Cement for Bituminous Plant Mix Base (Hot Mix) will be measured by the ton (metric ton) in accordance with the provisions of **Subsection 407.19**. Materials for

prime or tack coat, if specified, will be measured as prescribed in **Section 402** or **403**, respectively.

If recycled mix is permitted, the completed mix, including new mineral aggregate, planings, asphalt cement and additive, shall be measured by the ton (metric ton) in accordance with **Section 109**. For bidding purposes, the asphalt cement content of the specified mixes shall used in the chart below:

In the event that the Engineer sets an asphalt content other than that stated above, a price adjustment will be made based on the asphalt content set by the Engineer and the invoice price of the asphalt cement F.O.B. the asphalt plant. The price adjustment will be calculated according to the following formula:

$$PA = [IP \times (DA-BA) \times T] / 100$$

Where:

PA = Price Adjustment
IP = Invoice price of asphalt cement
DA = Percent asphalt set on the mix design
BA = Percent asphalt specified above to be used for bidding
T = Total tons(metric tons) asphalt mix for price adjustment

The liquid anti-strip additive will be measured by the gallon(liter) and paid as outlined in **Subsection 307.09**. Hydrated Lime will be measured by the ton (metric ton) and paid as outlined in **Subsection 307.09.**

No direct payment will be made for polymer or latex additives and cost thereof shall be included in the price bid for the modified asphalt cement or modified mixture.

307.09-Basis of Payment. The accepted quantities of Bituminous Plant Mix Base(Hot Mix) complete in place, will be paid for at the contract unit price per ton (metric ton) for the Aggregate and/or the Asphalt Cement. Accepted quantities of Prime Coat or Tack Coat will be paid for in accordance with the provisions of **Section 402** or **403**, respectively.

In cases where the effective combined specific gravity of the mineral aggregate exceeds 2.80, the tonnage(metric tonnage) of mineral aggregate, or plant produced mixture will be adjusted for payment by multiplying the tonnage(metric tonnage) of mineral aggregate, or plant produced mixture used by a specific gravity of 2.80 and dividing by the higher specific gravity.

The work required for preparation of subgrade, sub-base, base, or surface as provided for under **Subsection 307.06** will be measured and paid for in accordance with the provisions of the applicable Section or Subsection under which the work is performed.

If recycled mix is used, the accepted quantities of Bituminous Plant Mix Base(Hot Mix) complete in place, will be paid for at the contract unit price per ton (metric ton) of the total mix, which will include mineral aggregate, planings, asphalt cement and additive. Payment will be made to the Contractor for additional asphalt cement as provided for above at the purchase price F.O.B. the asphalt mixing plant, as verified by invoice, and no compensation will be allowed for further handling or processing. The Department will be reimbursed from monies due the Contractor for a

decrease in asphalt cement content in the amount equal to the purchase price F.O.B. the asphalt plant.

The liquid anti-strip additive will be paid for based on certified invoices of material cost not to exceed $15/gal. ($4/liter). Hydrated Lime anti-strip additive will be paid for based on certified invoices of material cost not to exceed $90/ton ($100/metric ton). This payment shall be full compensation for all labor, materials, equipment and other incidentals incurred in utilizing the anti-strip additive.

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SECTION 313-TREATED PERMEABLE BASE

313.01-Description. This work shall consist of the construction of treated permeable base composed of either a mixture of aggregate, Portland cement and water or a mixture of aggregate with asphalt binder. The Contractor may use either cement treated or asphalt treated permeable base as described in these specifications. It shall be constructed on a prepared sub-base in accordance with these Specifications and in reasonably close conformity with the lines, grades, thickness, and typical sections as shown on the Plans or as directed by the Engineer.

MATERIALS

313.02-Materials.

Materials	Subsection
Portland Cement, (Type I)	**901.01**
Aggregate for Portland cement Treated Mixture	**903.03**
Water	**918.01**
Asphalt Cement, Grade PG 64-22, 70-22, 76-22, 82-22	**904.01**
Aggregate for Bituminous Treated Mixture	**903.06**

313.03-Composition of Mixtures.

(a) Portland Cement Treated Permeable Base.

The water-cement ratio of the mixture shall be approximately 0.43 and shall contain no less than 282 lbs of Portland cement per yd^3 (168 kgs/m^3). The design shall produce a workable mixture having a compressive strength at 7 days of not less than 500 psi. (3.5 MPa) when tested in accordance with AASHTO T 22. The Contractor shall submit the proposed concrete mix design to the Engineer for approval in accordance with **Section 604**.

(b) Bituminous Treated Permeable Base.

Asphalt treated permeable base shall be Bituminous Plant Mix Base (Hot Mix) in accordance with **Section 307** and **407**. Liquid asphalt shall be PG64-22 and shall be used at the rate of 3% by weight of the total mixture. Asphalt content shall be such that all aggregate is visibly coated. The Contractor shall submit a mix design to the Engineer for approval in accordance with **Subsection 407.03** of these specifications.

EQUIPMENT

313.04-Equipment. All the equipment necessary for the satisfactory performance of this construction shall be on the project, and approved, before work will be permitted to begin. The equipment needed to construct the Portland cement treated base shall meet the requirements of **Subsection 501.04 (a)** and **(b)**. The spreading equipment shall meet either **Subsection 501.04 (d) 11** or **407.06.**

The equipment needed to construct the bituminous treated base shall meet the requirements of **Subsection 407.04** through **407.08**.

CONSTRUCTION REQUIREMENTS

313.05-Construction Requirements. Cement treated permeable base and asphalt treated permeable base shall conform to the requirements of **Section 309** and **Section 307** respectively unless otherwise stipulated below.

(a) Cement Treated Permeable Base.

1. **Consolidation and Finishing.** Immediately after placement of the cement treated permeable base, the mixture shall be consolidated using a steel-wheel roller weighing not less than 6 tons(5.5 metric tons). Rolling shall continue until maximum densification is achieved but shall cease immediately if aggregate breakage occurs. Vibratory rollers will not be allowed.
2. **Curing.** Immediately after spreading and compacting, the cement treated permeable base shall be cured by covering the entire surface and exposed edges with transparent or white polyethylene sheeting in accordance with **Subsection 501.18**. The polyethylene sheeting shall have a thickness of at least 4 mils(100 µm) and shall be held in place for a minimum of 7 days by a method approved by the Engineer. The surface of the cement treated permeable base shall be thoroughly wetted prior to placing the sheeting.

   Curing by the use of curing compounds is not allowed.

(b) Asphalt or Cement Treated Permeable Base.

The Contractor shall protect the treated permeable base from severe weather conditions particularly freezing rain, snow or icing and from contamination by dust, dirt, mud or other fine grained material. The base shall be protected from the time of placement until placement of the following pavement layer. Any portion(s) of the treated permeable base that becomes contaminated to the extent that drainage is reduced or inhibited, shall be removed and replaced at the Contractor's expense.

No traffic will be permitted on the treated permeable base. Equipment required to place the following layer of pavement will be allowed provided that it enters and exits as near as possible to

the paving operation. The Contractor at his expense shall repair any damage to the treated permeable base caused by the Contractor's equipment.

313.06-Limitations. If asphalt treated permeable base is used, the limitations prescribed in **Subsection 407.09** shall apply to this construction. No treated permeable base is to be placed that cannot be covered by the next course of pavement within the same construction season.

313.07-Surface Requirements. The finished surface of treated permeable base shall be uniform and shall not vary by more than ½ in. (13 mm) from the lower edge of a 12 ft. (3.6 m) straightedge. Surface testing with the 12 ft. (3.6 m) straightedge shall be performed in both transverse and longitudinal directions.

If the surface of the treated permeable base varies, more than ½ in. (13 mm) when tested as described above, the Contractor shall adjust the surface to a new grade established by the Engineer as follows:

(a) fill the low areas with Portland cement concrete during the concrete paving operation or

(b) apply emulsified asphalt, RS-2, at a rate not to exceed 0.2 gal./yd^2(1 liter/m^2)as determined by the Engineer over the specified low areas, and fill the low areas with size No. 8 mineral aggregate. The size No. 8 mineral aggregate shall be seated with a pneumatic tire roller.

No additional compensation will be allowed for leveling of the treated permeable base except on ramps that contain 4,500 yd^2 (4,000 m^2) or less of Portland cement concrete pavement. Measurement and payment for additional concrete used on these ramps shall be as specified in **Subsection 501.25** and **501.26**.

313.08-Tolerance in Pavement Thickness. Treated permeable base shall be placed to the thickness designated on the Plans. Before any further work is begun, the Contractor shall take core samples from the treated permeable base at locations established by the Engineer. Locations for coring will be determined in accordance with the provisions of **Subsection 501.24**. All core samples taken by the Contractor will be given to the Engineer for verification of base thickness. Adjustment of the contract unit price will be made in accordance with **Subsection 501.26** if the base thickness is determined by the Engineer to be deficient.

COMPENSATION

313.09-Method of Measurement. Treated permeable base shall be measured by the yd^2(m^2) complete in place for the width and thickness specified.

313.10-Basis of Payment. The accepted quantities of treated permeable base shall be paid for at the contract unit price per yd^2(m^2), complete in place. Such payment shall be full compensation for all materials, labor, equipment and incidentals required to complete the work. However, the provisions of **Subsection 501.26 (b)** shall apply for any base found deficient in thickness by more than ¼ in. (6 mm). No additional payment over the contract unit price will be made for base, which has an average thickness in excess of that shown on the Plans.

If the Department orders any increase or decrease in the cement content of the Cement Treated Base from the approved mix design, measurement and payment for this change shall be computed in accordance with **Subsection 501.25** and **501.26** of the Standard Specifications.

All cost of taking cores for verification of pavement thickness shall be included in the contract unit price of treated permeable base.

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SECTION 407-BITUMINOUS PLANT MIX PAVEMENTS (GENERAL)

407.01-Description. These Specifications include general requirements that are applicable to all types of bituminous pavements of the plant mix type, irrespective of gradation of aggregate, kind and amount of bituminous material, or pavement used. Deviations from these general requirements will be indicated in the specific requirements for each type.

This work shall consist of 1 or more courses of bituminous mixture constructed on the prepared foundation in accordance with these Specifications and the specific requirements of the type under contract, and in reasonably close conformity with the lines, grades, typical cross sections and rate of application or thickness shown on the Plans or established by the Engineer.

MATERIALS

407.02-Materials. The individual materials shall meet the applicable requirements of the following Sections or Subsections of these Specifications:

Material	Section or Subsection
Aggregates	**903**
Mineral Filler	**903.16**
Bituminous Materials	**904**
Chemical Additive	**918.09(B)**

Aggregate shall be separated into coarse and fine aggregate stockpiles. When coarse aggregate is stockpiled by means causing segregation, it shall be separated into coarse and medium coarse stockpiles.

Each size and type of aggregate shall be stocked in a separate pile, bin, or stall. The storage yard shall be maintained in an orderly condition with a walkway between stockpiles that are not separated by partitions. The stockpiles shall be readily accessible for sampling.

The mineral aggregate will be conditionally accepted for quality in the stockpile at the producer's site. The bituminous material may be conditionally accepted at the asphalt terminal. Acceptance of the aggregate gradation and asphalt cement content shall be determined from hot bin samples or sample(s) taken from the completed mix at the asphalt plant after it has been loaded onto the trucks for transport to the project as specified herein.

When anti-stripping additive, other than hydrated lime, as described in **Subsection 918.09(B)** is required, it shall be added by approved in-line blending equipment at the Contractor's mixing plant or by injection at the asphalt terminal. When a Performance Grade(PG) Asphalt mix with properties greater than that of PG 64-22 is called for on resurfacing plans and is the only asphalt grade on the project, the contractor has the option of using either the asphalt grade shown on the plans or an asphalt grade equal

to or better than PG 64-22 for driveways and business entrances unless otherwise directed by the Engineer. The material will be paid for at the same unit price as bid for the asphalt and/or asphalt mix. The material tickets shall be marked "**FOR DRIVEWAYS AND BUSINESS ENTRANCES ONLY**" at the point of delivery.

407.03-Composition of Mixtures.

(A) General:

The bituminous mixture shall be composed of a combination of aggregate(coarse, fine, or mixtures thereof), mineral filler if required, anti-strip additive if required, and bituminous material. The several aggregate fractions shall be sized, uniformly graded and combined in such proportions that the resulting mixture will meet the grading and physical properties of the approved Job Mix Formula.

(B) Gradation and Bituminous Material Requirement:

In all cases, the requested aggregate gradation and bituminous material percentages shown on the Job Mix Formula shall be within the Design Ranges shown in **Section 903** and **Sections 307** and **411**, respectively. The Contractor will set a recommended asphalt cement content on all mixes with the final optimum asphalt cement content to be determined by the Engineer.

(C) Job Mix Formula:

1. General:

At least 14 working days prior to the scheduled start of production of any asphaltic paving mixture, the Contractor shall submit in electronic form(e-mail or on a floppy disk) a proposed Job Mix Formula and Laboratory Design, where applicable, prepared in accordance with the Marshall Method of Mix Design (AASHTO T 245), as modified by TDOT, or by Gyratory Compaction (AASHTO T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by means of the Superpave Gyratory Compactor). When the gyratory compaction method is used, trial blends with at least 4 different asphalt contents (at least 2 above the optimum and 2 below the optimum) shall be made and the specimens shall be compacted to 65 gyrations with the optimum asphalt content and mixture volumetrics determined at that compaction level. If the specification requirements are not met, it will be necessary to make adjustments to the aggregate types and proportions. In addition the Contractor shall submit an asphalt barge certification with temperature-viscosity curve for each mixture to the Engineer for approval. A sample of each material to be used in the mix shall be delivered to the location designated by the Engineer

The following information shall be furnished:

a. The specific project on which the mixture will be used.
b. The source and description of all materials to be used in the mix.
c. The gradations and approximate proportions of the raw materials as intended to be combined in the paving mixture.
d. A single percentage of the combined mineral aggregate passing each specified sieve. The combined aggregate gradation shall be plotted on a gradation chart with sieve sizes raised to the 0.45 power to assure a well graded mix.
e. The Loss on Ignition (L.O.I.) results on the combined aggregate of the 411 Grading D mix used as a wearing course.
f. The Bulk Specific Gravity, Apparent Specific Gravity and absorption on the combined mineral aggregate in the paving mixture (AASHTO T 84 and T 85)
g. The fractured face count and glassy particle count of the plus No. 4 material, if applicable.
h. A single percentage of asphalt by weight of total mix intended to be incorporated in the completed mixture.
i. The dosage rate and source of anti-stripping additive, if required, meeting the requirements of **Section 918.09 (B)**, to be added to the asphalt.
j. The maximum specific gravity of the asphalt mixture (AASHTO T 209).
k. A single temperature at which the mixture is intended to be discharged from the plant.
l. Evidence that the completed mixture will conform to all specified physical requirements set forth in **Subsections 903.06 and 307.03 (a)** or **903.11** and **411.03 (b),** except the stability and flow requirements will be waived for mixes designed following AASHTO T312 and the resistance to rutting requirements for surface mixtures must be met.
m. The tensile strength ratio (TSR) indicating the stripping and moisture susceptibility characteristics of the mix.
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%.

The laboratory mix and compaction temperatures shown on the Job Mix Formula shall be established in accordance with the following Table A:

Table A

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

Any additional testing of the mix in a laboratory shall be performed using the laboratory mix and compaction temperatures listed on the approved Job Mix Formula. A tolerance of ± 5° for each temperature will be allowed.

The Laboratory Design must be prepared and signed by a Certified Laboratory Technician. To be certified, the technician must have completed the Marshall Method of Mix Design School conducted by the Department, including the written and lab performance testing.

2. Revision of Job Mix Formula:

The approved job mix formula shall remain in effect until a change is authorized in writing by the Engineer. The Contractor, at any time after construction has started, may request that the job mix formula be revised, providing evidence is shown that the revision is necessary and the revised aggregate gradation will meet all applicable gradation requirements.

A revised Job Mix formula will be necessary, if during the test strip construction and mix design/production verification procedure, changes to the mixture are made to comply with the specified criteria.

A new design will be required for any change in source of materials. All requests for design mix adjustments, redesigns and new design mixes will be submitted in writing to the Engineer for approval.

3. Resistance to Plastic Flow:

The submitted job mix formula shall include test data showing that the material as produced will meet the requirements specified in **Subsections 307.03 (a)** or **411.03 (b)** when tested in accordance with AASHTO T-245. The bulk specific gravity of the laboratory compacted bituminous mixture(Marshall specimens) shall be determined in accordance with AASHTO T-166. Mixes designed

according to AASHTO T-312 shall be exempt from AASHTO T-245.

For surface mixtures with greater than 5000 ADT, designed with the gyratory compactor, AASHTO T-312, the submitted job mix formula shall include enough raw materials (aggregate and asphalt cement) so that the TDOT Central Laboratory may conduct rut testing using the Asphalt Pavement Analyzer (APA). TDOT will compact specimens to 7±1 % air voids and conduct the tests. Tests will be conducted at 147° F, with 100-psi hose pressure and 100 pounds wheel load. After 8000 cycles the maximum allowable rut depth will be 0.35 in. for roads with ≥ 10,000 ADT and 0.40.in. with roads with 5,000 to 10,000 ADT. A new mixture design will be required if the mixture fails to meet the APA rut testing requirements.

The percent voids in the total mix shall be based on the maximum specific gravity of the bituminous mixture (Rice Gravity) as determined by AASHTO T-209. The voids in the mineral aggregate(VMA) shall be calculated using the effective specific gravity of the aggregates.

(D) Contractor's Quality Control:

All materials will be approved for acceptance through the Department's Acceptance Procedures specified herein. The Engineer will be responsible for determining the acceptability of the construction and materials incorporated therein. The Contractor will be responsible for the quality of construction and materials incorporated therein. All quality control sampling and testing will be accomplished on a random basis in accordance with the Contractor's approved quality control plan. The Department will perform all necessary sampling and testing for acceptance purposes on a random basis in addition to monitoring and observing the Contractor's quality control test procedures and results. The requirements for the Contractor's quality control sampling and testing will remain in effect until final project acceptance.

LOT sizes will be as specified in **Subsection 407.20(B) (1).**

All sampling and testing of materials for the Contractor's Quality Control and the Department's Acceptance shall be performed in strict conformance with the Department's Policies on Sampling and Testing Procedures and Sampling of Asphalt Mixes for Verification of Laboratory Design.

1. Acceptance Plans:

(a) Payment Based on Acceptance Results:

The payment for each LOT of material will be adjusted on the basis of acceptance test results in accordance with the requirements specified hereinafter in the various sections of these specifications.

(b) Resampling of LOTS:

It is the intent of these specifications that each LOT of material will meet specification requirements at the time of acceptance testing. No check samples will be taken for acceptance purposes.

(c) Referee System:

All acceptance samples will be split and 1/2 of the sample will be retained by the acceptance inspector. In the event that the results of an acceptance test are questioned, the remaining 1/2 of the acceptance sample will be submitted to the central laboratory for testing. The results obtained by the central laboratory will be used in the evaluation of the quality of the lot.

2. Quality Control by the Contractor:

When reclaimed asphalt pavement is approved for use as a component material in a hot bituminous mixture, the Contractor's Quality Control Plan shall include determination of the gradation and asphalt content of the reclaimed asphalt pavement material at a minimum frequency of 1 stockpile sample per 2,000 tons(2,000 metric tons) used in the mixture.

After the job mix formula has been approved, the Contractor shall furnish material that meets the approved job mix formula within the acceptance range shown in **Table 407-2**. The process will be considered out of control when test results from a LOT fall below the 90% pay factor limit for the values in **Table 407-2**. The Contractor shall cease plant operations until such time as he can demonstrate that he can and will control the process.

The Contractor shall provide and maintain a quality control system that will provide reasonable assurance that all materials conform to specification requirements. This quality control system shall conform to the "Contractor Quality Control System", which is defined as follows:

CONTRACTOR QUALITY CONTROL SYSTEM

(a) Scope:

This establishes minimum requirements and activities for a Contractor Quality Control System. These requirements pertain to the inspections and tests necessary to substantiate material and product conformance to contract requirements and to all inspections and tests required by the contract.

(b) Functions and Responsibilities:

1. The Contractor will submit all mix designs to the Engineer for approval. The Department will approve

design mixes, conduct acceptance tests, inspect plants, and monitor control of the operations to assure conformity with the specifications. The Contractor will be responsible for setting of all dials, gauges, scales, and meters.

2. At the preconstruction conference, the Contractor shall submit in writing his proposed Quality Control Plan for approval of the Engineer. The plan shall contain the sampling, testing, inspection and the anticipated frequencies of each that the Contractor will follow to maintain process control. The required series of sampling, testing, and inspecting activities are shown in **Table 407-1** below**.**

Table 407-1

REQUIRED ITEMS FOR A
CONTRACTOR QUALITY CONTROL PLAN

A. All Types of Plants

1. Stockpiles
   (a) Determine gradation of all incoming aggregates
   (b) Inspect stockpiles for separation, contamination, segregation, etc.
   (c) Conduct a fractured face count when gravel is used as coarse aggregate
   (d) Determine the percent of glassy particles in slag coarse aggregate
   (e) Determine gradation and asphalt content of reclaimed asphalt pavement when used as a component material
2. Cold Bins
   (a) Calibrate the cold gate settings
   (b) Observe operation of cold feed for uniformity
   (c) Insure that bins have proper dividers to prevent materials from spilling over into adjacent bins.
3. Dryer
   (a) Observe pyrometer for aggregate temperature control
   (b) Observe efficiency of the burner.
   (c) Determine the percent dust coating on +4 material
   (d) Check dried aggregate for contamination due to incomplete combustion of fuel

Table 407-1
(Cont'd)

4. Hot Bins

   (a) Determine gradation of aggregates in each bin
   (b) Determine theoretical combined grading

5. Bituminous Mixture

   (a) Determine percent bitumen
   (b) Determine mix gradation
   (c) Check mix temperature
   (d) Determine percent moisture in mix when reclaimed asphalt pavement is a component material
   (e) Determine Loss-On-Ignition (L.O.I.) of aggregates in mix where applicable
   (f) Check the mix for uncoated
   (g) Insure that handling procedures do not contribute to segregation of the mix.

B. Batch Plants

1. Batch Weights--Determine percent used and weight to be pulled from each bin to assure compliance with Job Mix Formula
2. Check mixing time (both dry and wet)
3. Check operations of weigh bucket and scales
4. Document accuracy of all weighing and metering devices for
   (a) Asphalt cement
   (b) Aggregate
   (c) Anti-strip additive

C. Drum Mixer Plant

1. Calibrate the cold feed and prepare a calibration chart for each cold gate
2. Develop information for the synchronization of the aggregate feed and the bituminous material feed
3. Determine moisture content of aggregate being fed into dryer
4. Determine the percent dust coating on dried +4 material
5. Check dried aggregate for incomplete combustion of fuel
6. Document accuracy of all weighing and metering devices for:
   (a) Asphalt cement
   (b) Aggregate
   (c) Anti-strip additive

The activities shown in **Table 407-1** are considered to be normal activities necessary to control the production of asphalt concrete at an acceptable quality level. It is recognized, however, that depending on the type of process or materials, some of the activities listed may not be necessary and in other cases, additional activities may be required. The frequency of these activities will also vary with the process and the materials. When the process varies from the defined process average and variability targets, the frequency of these activities will be increased until the proper conditions have been restored.

The Contractor or Producer shall plot and keep up-to-date control charts for all Quality Control Sampling and Testing. Control charts shall be provided for the following:

(a) Extracted asphalt content
(b) Mix gradation
(c) Dust to asphalt ratio
(d) Maximum theoretical gravity (when required)
(e) Voids in total mix (when required)
(f) Stability (when required)

The Contractor shall post all current control charts in the asphalt lab where they can be seen.

The Contractor shall be responsible for the formulation of all design mixes with the exception of plant mix seal coat mixes. No lab design is required for 307 Grading A, AS and ACRL mixes. However, the Contractor shall establish the anti-strip additive dosage rate and verify compatibility of mixture materials by the ten minute boil test in accordance with this Subsection. Contractor-furnished design mixes must be submitted to the Department for approval, prior to their use. The Contractor shall be responsible for the process control of all materials during handling, blending, mixing, and placing operations.

(c) Quality Control System:

1. General Requirements. The Contractor shall furnish and maintain a quality control system that will provide reasonable assurance that all materials and products submitted to the Department for acceptance, conform to the specification requirements.

   The Contractor shall have a Quality Control Technician, who is currently certified by the Department as a Certified Asphalt Plant Technician, available at the asphalt plant at all times the Contractor is producing asphalt mix for the Department. When it becomes evident to the Department that the Quality Control Technician cannot perform as required by the position,

the Department will revoke the certification and require replacement with a certified technician. The Contractor's quality control procedures, inspection, and tests shall be documented and that information shall be available for review by the Department throughout the life of the contract.

2. Documentation. The Contractor shall maintain adequate records of all inspections and tests. The records shall indicate the nature and number of tests made, the number and type of deficiencies found, and the nature of corrective action taken as appropriate. The Contractor's documentation procedures will be subject to the review and approval of the Department prior to the start of the work and to compliance checks during the progress of the work. Copies of all charts and records documenting the Contractor's quality control tests and inspections shall be furnished to the Engineer daily.
3. Charts and Forms. All conforming and nonconforming inspections and test results shall be recorded on approved forms and charts which shall be kept up to date and complete. These test results shall be maintained at the Contractor's plant site laboratory and shall be available at all times to the Engineer during the performance of the work. Test results for the various materials and mixtures shall be charted on forms that are in accordance with the applicable requirements of the Engineer. An example of each chart and form to be used by the Contractor will be furnished by the Engineer. The Contractor will furnish his own supply of the charts and forms.
4. Corrective Actions. The Contractor shall take prompt action to correct any errors, equipment malfunctions, process changes, or other assignable causes which have resulted or could result in the submission of materials, products, and completed construction which does not conform to the requirements of the specifications. When it becomes evident to the Engineer that the Contractor is not controlling his process and is making no effort to take corrective actions, the Engineer will require that plant operations be ceased until such time as the Contractor can demonstrate that he can and will control the process.
5. Laboratories With Measuring and Testing Equipment. The Contractor shall furnish a fully equipped laboratory at the production site in accordance with the provision of **Subsection 106.06**. This facility may be permanent or portable. The laboratory shall be furnished with the necessary testing equipment and supplies for performing Contractor Quality Control sampling and testing as well as Department Acceptance sampling and testing. To assure accuracy, the testing equipment will be checked

periodically in accordance with the TDOT Procedure for Qualified Laboratories.

6. Sampling and Testing. Sampling and testing methods and procedures used by the Contractor to determine quality conformance of the materials and products shall be in accordance with **Subsection 106.04** Sampling and Testing, or Inspection. The Contractor's Quality Control Plan will include the taking of samples for material characteristics on a random basis and the plotting of the test results on control charts.
7. Alternative Procedures. The Engineer may approve the use of alternative sampling methods, procedures, and inspection equipment when such procedures and equipment provide, as a minimum, the quality assurance required by the contract documents. Prior to applying such alternative procedures, the Contractor shall describe them in a written proposal and shall demonstrate for the approval of the Engineer that their effectiveness is equal to or better than the contract requirements.
8. Mix Design/Production Verification. The Contractor will be required to sample and test asphaltic concrete base and surface mixes throughout production to verify that the mix being produced is within the criteria listed below. This information shall also be recorded on control charts. This requirement applies only to mixes designed in keeping with the Marshall Method of Mix Design. The following will be required for all interstate projects, any project with a current Average Daily Traffic (ADT) exceeding 12,000 and any project utilizing modified asphalt cements but in no case shall the following apply to any individual mix with a quantity of 1,000 tons(metric tons) or less:

Maximum Theoretical Gravity:	± .025 of Mix Design Value
Voids in Total Mix:	3.0% to 5.5%
Voids in Mineral Aggregate:	Minimum as noted in Specifications
Marshall Stability:	Minimum as noted in Specifications
Dust/Asphalt Ratio:	As noted in Specifications

The asphalt pavement mix design/production verification procedure shall consist of the following:

a. Mix designs shall be submitted to the Engineer for approval prior to mix production. Once approved,

sufficient mix shall be produced to construct a test strip as noted in **Subsection 407.15**.

b. The Contractor will perform maximum theoretical gravity and gradation tests from material produced for constructing the test strip. These tests will be performed under the Engineer's observation by a Quality Control Technician, who is currently certified by the Department as a Certified Asphalt Mix Design Technician.

c. The equipment and procedures used for determining the theoretical gravity of the mix shall conform to AASHTO T 209. The equipment for determining bulk specific gravity shall conform to AASHTO T 312 when designing with the gyratory compactor.

d. No more than 500 tons(500 metric tons) of mix shall be placed until the verification testing, with the exception of TSR, is complete. If the test results for the produced mix are within the previously defined limits required for production and mix density requirements are met, the Contractor will be allowed to proceed. If not, a revised design will be required prior to start up and another evaluation process will be required for the revised design. No more than 100 tons(100 metric tons) of mix shall be placed during this trial. This process shall be repeated until an acceptable mix can be produced. All test strip and mixture design/production verification material will be subject to applicable price adjustments or removal at no cost to the Department. If the TSR results are not in compliance with the specifications, production shall immediately stop until mixture adjusts are made.

e. During construction, the Contractor will be required to perform verification testing for each 1/2 day's production for mix quality control. A random numbers table shall be used to determine when to collect samples for testing.

1. When the test results are outside the allowable criteria, a subsequent sample shall be immediately obtained and tested for compliance.
2. If the subsequent test results are within allowable limits, the Contractor may continue mix production.
3. If the subsequent test results are outside allowable limits, production of mix shall not continue until the Contractor has demonstrated to the Engineer that adequate corrective action has been taken. The Contractor will then be permitted to produce sufficient mix, not to exceed 100 tons(100 metric

tons), to provide a representative sample for determining stability, voids in the total mix, and the dust/asphalt ratio. Production of mix shall not continue until test results indicates compliance with the previously defined requirements and density meets specifications.

(E) Testing Procedures:

The Loss on Ignition(LOI), Tensile Strength Ratio(TSR), Stripping Test and the Coating Tests shall be determined in accordance with the following:

Tensile Strength Ratio

Testing for stripping and moisture susceptibility of the mixture shall be in accordance with ASTM D 4867, Standard Test Method for Effect of Moisture on Asphalt-Concrete Paving Mixtures(Root-Tunnecliff Procedure).

When a polymer modified asphalt cement is specified, a minimum tensile strength of 100 psi(690 kPa) and a minimum tensile strength ratio(TSR) of 80% for the conditioned specimen shall be required when testing for stripping and moisture susceptibility in accordance with Root-Tunnecliff Procedures as described above. When a non-polymer modified asphalt cement is specified, the above conditions will be required except the minimum tensile strength shall be 80 psi(550 kPa).

Ten Minute Boil Test (Stripping)

Field Test

The completed mix will be tested for stripping at the asphalt plant as follows. From a sample of the completed mix, visually select a minimum of 50 grams of the plus No. 4(4.75 mm) material and place immediately in boiling water. Continue to boil for 10 minutes, pour off water and place coated aggregate on a paper towel. The coated aggregate shall not show any evidence of stripping as determined by a visual inspection.

Laboratory Test

The dosage rate will be determined in the laboratory by the following: Fifty grams of the mineral aggregate passing the 1/2 in. (12.5 mm) sieve and retained on the No. 4(4.75 mm) sieve shall be washed and surface dried. The selected aggregate shall be thoroughly coated with the blend by stirring of the mixture heated to 250° F(120° C). The material shall be placed immediately in boiling water. Continue to boil for 10 minutes, pour off water and place coated aggregate on a paper towel. The coated aggregate shall not show any evidence of stripping as determined by a visual inspection.

Coating Test

At least a 1500 gm aggregate sample of plus No. 4(4.75 mm) material shall be taken from each hot bin, after drying in a batch plant, or at least a 5,000 gm aggregate sample of plus 4 material shall be taken from material dried in a dryer drum plant. The aggregate shall be gently manipulated on the No. 4(4.75 mm) screen to separate it from all free fines. Transfer the aggregate retained on the No. 4(4.75 mm) screen to a tared No. 8(2.36 mm) screen and determine its dry weight. Thoroughly wash the material retained on the No. 8(2.36 millimeters) screen to remove all fines. Dry the aggregate retained on the No. 8(2.36 mm) screen and calculate the percent loss.

Test for Percent loss on ignition of the Mineral Aggregate in a 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.

Calculations:

$$\text{Percent Loss on ignition} = \frac{(A-B) \times 100}{A}$$

Where A = weight of sample before ignition (corrected for filter aid)
B = weight of sample after ignition (corrected for filter aid)

EQUIPMENT

407.04-Bituminous Mixing Plant. Sufficient storage space shall be provided for each size aggregate. The different sizes shall be kept separated until they have been delivered to the cold elevator or belt feeding the dryer. The storage yard shall be maintained neat and orderly and the separate stockpiles shall be readily accessible for sampling.

Plants used for the preparation of bituminous mixture shall conform to all requirements under (a). In addition, batch mixing plants shall conform to the requirements under (b), continuous mixing plants shall conform to the requirements under (c), and dryer-drum mixing plants shall conform to the requirements under (d).

(a) Requirements for All Plants.

Mixing plants shall be of sufficient capacity and so coordinated to adequately handle the proposed bituminous construction.

1. Equipment for preparation of bituminous material.
   Tanks for the storage of bituminous material shall be equipped to heat and hold the material at the required temperatures. The circulating system for the bituminous material shall be designed to assure proper and continuous circulation during the operating period. Provisions shall be made for measuring and sampling the contents of storage tanks.

2. Feeders for dryer.
   Separate feeders shall be provided for each size aggregate, and each size shall be fed onto the belt going to the dryer by mechanical feeders with separate adjustable gates. The feeders shall be capable of delivering the separate aggregates onto the belt in proper proportions.
   Adequate means shall be provided to assure a constant and uniform flow of material from each bin. Bins containing fine aggregate shall be equipped with vibrators if necessary.
   The Contractor will not be permitted to blend or mix different aggregates or different sizes of the same aggregates with clam shells, bulldozers, high lifts or similar equipment.
   The aggregate shall be fed uniformly into the dryer so that a uniform production and uniform temperature may be obtained.

3. Dryer.
   The plant shall include a dryer or dryers that agitate the aggregate continuously during the heating and drying process; it shall be capable of heating and drying all aggregates to the temperature required, and shall be capable of supplying the mixing unit continuously at its operating capacity. Dryers shall be constructed and operated so that aggregates will not be contaminated with unburned fuel.

4. Screens.
   Plant screens, capable of screening all aggregates to the specified sizes and proportions and having normal capacities in excess of full capacity of the mixer, shall be provided.
   A consistent carry-over, but not to exceed 20%, will be allowed on any screen. If any bin contains more than 20% of material which is undersized for that bin, the bin shall be

emptied and correction of the cause for such condition shall be made.

Approved scalping screens shall be required on all dryer-drum mixing plants, but additional screens will not be required.

5. Bins.

The plant shall include storage bins of sufficient capacity to supply the mixer when it is operating at full capacity. Bins shall be arranged to assure separate and adequate storage of appropriate fractions of the mineral aggregates. Each bin shall be provided with overflow pipes of such size and at such location as to prevent backing up of material into other compartments or bins. Each compartment shall be provided with an outlet gate constructed so that when closed there shall be no leakage. The gates shall be cut off quickly and completely. The bins shall be constructed to provide adequate and convenient approved facilities for obtaining representative samples of aggregate from the full flow of each compartment. These bins shall not be required in an approved Dryer-Drum Mixing Plant. When mineral filler is used, separate dry storage shall be provided and the plant shall be equipped to uniformly and accurately feed the filler into the mixer.

6. Bituminous control unit and Anti-strip additive (ASA) systems.

Satisfactory means, either by weighing or metering, shall be provided to obtain the proper amount of bituminous material in the mix within the tolerance specified. Means shall be provided for checking the quantity or rate of flow of bituminous material into the mixer.

Where anti-stripping additive, other than hydrated lime, as described in **Subsection 918.09(B)** is required, it shall be added by approved in-line blending equipment. The Contractor shall have a storage tank for the ASA that can maintain a constant temperature without overheating the additive. The additive shall be stored in accordance with the Manufacturers recommendations and in no case shall it be stored above 150 ºF. The in-line blending equipment on drum plants shall have a totalizing "flow meter" capable of measuring the actual flow rate within the production range of 0.00 to 1.00 gallons per minute at increments of 0.05 gallons. Batch plants must have a totalizing flow meter. The totalizer shall display the total gallons of material dispensed. The dispenser and/or pumps shall be capable of adding the heat stable anti-stripping additive within a tolerance of 10 % of the specified rate.

7. Thermometric equipment.

An armored thermometer of adequate range in temperature reading shall be fixed in the bituminous feedline at a suitable location near the charging valve at the mixer unit. The plant shall also be equipped with an approved thermometric instrument so placed at the discharge chute of the dryer as to register automatically or indicate the temperature of the heated aggregates. With the approval of the Engineer, the thermometric instrument may be placed within the fines bin.

The plant shall be equipped with an approved automatic recording and regulating apparatus for control of the temperature of the aggregates.

8. Dust Collector.

The plant shall be equipped with a dust collector constructed to uniformly waste or return to the dried aggregate all or any part of the material collected. Collected baghouse fines intended for recirculation into the mix shall be handled as if it were mineral filler or fed by another suitable method approved by the Engineer. Means shall be provided to calibrate and adjust the dust fed from a baghouse.

9. Safety Requirements.

Adequate and safe stairways to the mixer platform and sampling points shall be provided. Guarded ladders to other plant units shall be placed at all points where accessibility to plant operations is required. Accessibility to the top of truck bodies shall be provided by a platform or other suitable device to enable the Engineer to obtain samples and mixture temperature data. A hoist or pulley system shall be provided to raise scale calibration equipment, sampling equipment and other similar equipment from the ground to the mixer platform and return. All gears, pulleys, chains, sprockets, and other dangerous moving parts shall be thoroughly guarded and protected. Ample and unobstructed space shall be provided on the mixing platform. A clear and unobstructed passage shall be maintained at all times in and around the truck loading area. This area shall be kept free of drippings from the mixing platform.

10. Field Laboratory.

The Contractor shall furnish a Type B field laboratory in accordance with the requirements **of Subsection 106.06.**

11. Surge and Storage Systems.

Surge or Storage systems may be used at the option of the Contractor provided each system is approved by the Department prior to use.

The surge and storage system shall be of such design that there is no appreciable difference between material being discharged from the bin or silo and material being discharged directly from the pugmill.

The surge bins and storage silos must be equipped with low and high mix level indicators. The low level indicator shall be placed at a location on the bin or silo that has been predetermined to prevent segregation of the mix.

The conveyor system used with the surge bins or storage silos shall be arranged in such a manner that samples of the mix or dry material may be conveniently taken from the pugmill.

Storage silos shall be closed, insulated, and heated in such a manner that localized heating does not occur. The storage silo shall be capable of being sealed to prevent oxidation of the mixture. Surge bins shall be equipped with a rain cover capable of preventing water from entering the mix in the bin.

Approval of a surge or storage system will be dependent upon inspection and tests that indicate that the system is capable of conveying, retaining, and delivering the bituminous mixture:

1. within the tolerance ranges as set forth on the Job Mix Formula;
2. without segregation;
3. without balling or hardening.

Approval of a surge or storage system may be withdrawn if tests and/or inspections indicate that the system is having a detrimental effect on the bituminous mixture.

Any bituminous mix which, in the judgment of the Engineer, is damaged in any way by the use of a surge or storage system will be rejected.

Platform truck scales meeting the requirements of **Section 109** shall be mounted under the loading hopper and shall be capable of recording tare and gross weights.

(b) Requirements for Batching Plants.

1. Plant Scales.

Dial scales shall be provided for weighing of all aggregates and mineral filler, in the suspended weigh box. Dial scales shall be of a standard make and of sufficient size that the numerals on the dial can be read at a distance of 25 ft. (8 m). The dials shall be of the compounding type having a full complement of index pointers. The value of the graduation of scales used in weighing amounts of aggregates less than 5,000 lbs. (2,500 kgs) shall not be greater than 5 lbs. (3 kgs); amounts of aggregates from 5,000 to 10,000 lbs. (2,500 to 5,000 kgs) shall not be greater than 10 lbs. (5 kgs);

amounts of aggregates in excess of 10,000 lbs. (5,000 kgs) shall not be greater than 0.1% of the capacity of the scales. Pointers which give excessive parallax errors shall not be used. All dial scales shall be so located that they will be in plain view of the operator at all times. When bituminous material is measured by weight, the asphalt weigh bucket shall be equipped with a separate dial scale with a minimum graduation not greater than 2 lbs. (0.9 kgs). All dial scales shall be accurate within a tolerance of 0.5%. Vibration shall be eliminated by setting the scales on a separate foundation, if required. Each installation of scales shall be provided with 10 standard 50 lb(25 kg) weights meeting the requirements of the U. S. Bureau of Standards) for calibrating and testing weighing equipment. Scales shall be inspected as often as the Engineer may deem necessary to assure their continued accuracy.

The Contractor shall provide an approved automatic printer system which will print the weights of the material delivered, when the system is used in conjunction with an approved automatic batching and mixing control system. Such weights shall be evidenced by a weigh ticket for each load.

2. Weigh box or hopper.

The equipment shall include a means for accurately weighing each size of aggregate and mineral filler in a weigh box or hopper suspended on scales. The weigh box or hopper shall be of ample size to hold a full batch without hand raking or running over. The gate shall close tightly so that no material is allowed to leak into the mixer while a batch is being weighed.

3. Bituminous control.

The bituminous material bucket shall be a non-tilting type. The length of the discharge opening or spray bar shall be not less than 3/4 the length of the mixer and it shall discharge directly into the mixer; the bituminous material bucket, its discharge valve or valves, and spray bar shall be adequately heated. Steam jackets, if used, shall be efficiently drainable and all connections shall be so constructed that they will not interfere with the efficient operation of the bituminous scales. The capacity of the bituminous material bucket shall be at least 15% in excess of the weight of bituminous material required in any batch. The plant shall have an adequately heated quick-acting, non-drip, charging valve located directly over the bituminous material bucket. When the bituminous material is metered, the indicator dial shall have a capacity of at least 15% in excess of the quantity of bituminous material used in a batch. The meter indicator

dial shall have a scale with divisions measuring in gallons equivalent to a weight sensitivity of 0.04% of the total batch weight. The meter shall be accurate within a tolerance of 0.5%. The controls shall be so constructed that they may be locked at any dial setting and will automatically reset to that reading after the addition of bituminous material to each batch. The dial shall be in full view of the mixer operator. The flow of bituminous material shall be automatically controlled so that it will begin when the dry-mixing period is over. All of the bituminous material required for 1 batch shall be discharged in not more than 15 seconds after the flow has started. The size and spacing of the spray bar openings shall provide a uniform application of bituminous material the full length of the mixer. The section of the bituminous line between the charging valve and the spray bar shall be provided with a valve, and the spray bar shall be provided with a valve and outlet for checking the meter when a metering device is substituted for a bituminous material bucket.

4. Mixer.

The batch mixer shall be an approved twin pugmill type, steam or hot oil jacketed, and shall be capable of producing a uniform mixture within the job mix tolerances. The mixer shall be so constructed as to prevent leakage of its contents. It shall be equipped with a sufficient number of paddles or blades set in the "run around" order and operated at such speed as to produce a properly and uniformly mixed batch. The depth of the material in the pugmill shall not be above the tips of the paddles. If not enclosed, the mixer box shall be equipped with a dust hood to prevent loss of dust.

The clearance of blades from all fixed and moving parts shall not exceed 1 in. (25 mm) unless the maximum diameter of the aggregate in the mix exceeds 1 1/4 in. (30 mm), in which case the clearance shall not exceed 1 1/2 in. (40 mm).

5. Control of mixing time.

The mixer shall be equipped with an accurate time lock to control the operations of a complete mixing cycle. It shall lock the weigh box gate after the charging of the mixer until the closing of the mixer gate, at the completion of the cycle. It shall lock the bituminous material bucket throughout the dry-mixing period and shall lock the mixer gate throughout the dry and wet-mixing periods. The dry-mixing period is defined as the interval of time between the opening of the weigh box gate and the start of introduction of bituminous material. The wet-mixing period is the interval of time between the start of introduction of bituminous material and the opening of the mixer gate. The control of the timing shall be flexible and capable of being set at intervals of 5 seconds or less

throughout a total cycle of up to 3 minutes. A mechanical batch counter shall be installed as a part of the timing device and shall be so designed as to register only batches that have been mixed for the full time interval. The setting of time intervals shall be performed in the presence of and at the direction of the Engineer, who shall then lock the case covering the timing device until such time as a change is to be made in the timing periods.

6. Operator's Platform Observation House.

The plant shall be equipped with a scale observer's house. The house shall be mounted on or near the weigh platform and shall be so situated that the aggregate and asphalt scales, asphalt thermometer, and pyrometer are plainly visible from within the house.

The house shall be soundly constructed of approved materials with at least 45 s.f. (4 m^2) of floor space and air conditioned by a unit of at least 12,000 B.T.U. (12,700 kilojoules). If the Contractor so desires, he may install all batch controls in the house. However, it shall not be used for storage or purposes other than to house the batch controls, plant operator and Department Inspector. If the Contractor elects not to move the plant controls into the house, it shall be so situated as to give the scale inspector full view of the control panel.

When the scale-watchers house is located on the asphalt plant it shall be equipped with an adequate secondary means of escape in the event of fire or explosion.

The house will be considered as part of the plant and no direct payment will be made for its construction and maintenance.

(c) Requirements for Continuous Mixing Plants.

1. Aggregate proportioning.

The plant shall include means for accurately proportioning each size of aggregate. The plant shall have a feeder mounted under each compartment bin. Each compartment bin shall have an accurately controlled individual gate to form an orifice for measuring volumetrically the material drawn from each compartment. Bins shall be equipped with adequate tell-tale devices to indicate the position of the aggregates in the bins at the lower quarter points.

The feeding orifice shall be rectangular with 1 dimension adjustable by positive mechanical means provided with a lock. Indicators shall be provided for each gate to show the respective gate opening in inches(millimeters).

Mineral filler shall be fed into the mixer continuously and uniformly in the proportion set out in the formula for the job mix, and in a manner satisfactory to the Engineer.

2. Weight calibration of aggregate feed.
   The plant shall be equipped with an approved revolution counter in satisfactory working condition. The plant shall include a means for calibration of gate openings by weighing test samples. Provision shall be made so that materials fed out of individual orifices may be bypassed to individual test boxes. The plants shall be equipped to handle conveniently individual test samples weighing not less than 200 lbs. (100 kgs). Accurate scales shall be provided by the Contractor to weigh such test samples.

3. Synchronization of aggregate feed and bituminous material feed.
   Satisfactory means shall be provided to afford positive interlocking control between the flow of aggregate from the bins and the flow of bituminous material from the meter or other proportioning device. This control shall be accomplished by mechanical means or by any other positive method satisfactory to the Engineer.

4. Mixer.
   The plant shall include a continuous mixer of an approved twin pugmill type, adequately heated and capable of producing a uniform mixture within the job mix tolerances. The paddles shall be adjustable for angular position on the shafts and reversible to retard the flow of the mix. The mixer shall have a manufacturer's plate giving the net volumetric contents of the mixer at the several heights inscribed on a permanent gauge. Charts shall be provided showing the rate of feed of aggregate per minute for the aggregate being used. Determination of the mixing time shall be by weight method, using the following formula (the weights shall be determined for the job by tests made by the Engineer) where:

Mixing time in seconds =

$$\frac{\text{Pugmill dead capacity in lbs(kgs)}}{\text{Pugmill output in lbs(kgs) per second}}$$

5. Surge hopper.
   The mixer shall be equipped with a discharge hopper with dump gates which will permit rapid and complete discharge of the mixture and of such size and design that no segregation of the mixture occurs.

6. Platform Truck Scales.

Platform truck scales shall meet the requirements of **Section 109**.

(d) Requirements for Dryer-Drum Mixing Plants.

1. Control of Aggregate.

The aggregates shall be stockpiled and handled so as to prevent any significant amount of segregation, contamination or degradation. Stockpiles shall be constructed in accordance with **Subsection 903.20**.

Each aggregate shall have a separate feeder that has a positive feed that can be easily and accurately calibrated. The plant shall have a flow indicator and an audible warning device on each separate feeder to assure a constant and uniform flow of aggregate from each bin onto the belt.

Mineral filler, if required, shall be fed into the mixer continuously and uniformly in the proportion set out in the formula for the job mix, and in a manner approved by the Engineer.

2. Synchronization of Aggregate Feed and Bituminous Material Feed.

Satisfactory means shall be provided to afford a positive interlocking control between cold aggregate feed and asphalt. The control setting for the asphalt flow will be based on the dry weight of the aggregate. There must be an acceptable method provided for proportioning asphalt flow as variations in aggregate flow take place. A metering system will be provided to measure the flow of asphalt into the drum and an approved method of checking and calibrating the metering system shall be located in the control house. An automatic interlock system will be provided that will shut off the asphalt flow and the burner when the aggregate flow ceases.

3. Temperature Control.

Dryer-Drum Mixing Plants shall be equipped with a recording pyrometer or other approved thermometric instrument sensitive to a rate of temperature change of not less than 10° F(6° C) per minute. The system shall be equipped with automatic burner controls and shall provide for temperature sensing of the bituminous mixture at discharge from the drum.

4. Scales and Metering Systems.

The Contractor shall be required to furnish weights and charts for checking the accuracy of the belt scales and the bituminous metering system. The scales and meters shall have an accuracy within a tolerance of 0.5%.

The belt scale which weighs the combined aggregate shall be in accordance with the **National Institute of Standards and Technology Handbook 44.**

5. Sampling Devices.
   There shall be an approved method provided for sampling individual cold feeds and sequential sampling of aggregate and asphalt under full scale production. The sampling device and procedures used shall be approved by the Engineer and shall be such that the normal operation will not be interrupted.

6. Platform Scales.
   The Contractor shall make certified platform scales available for checking the asphalt metering system and for weighing or checking loads of asphalt mix in accordance with Department policy.

7. Silos or Surge Bins.
   Surge or storage silos shall meet the requirements of **Subsection 407.04(a)11** or if a silo is not provided, an approved surge bin capable of holding sufficient mix to allow the plant to operate at an efficient rate of production shall be provided, and the system shall be capable of conveying, retaining and delivering the bituminous mixture so that it is within the job mix formula and without segregation. Any mix that is damaged in any way will be rejected.
   The surge bin may include a weighing system. If a weighing system is included in the surge system, it shall be subject to approval of the Engineer and the Contractor shall provide approved weights for checking the weighing system. The system shall be checked in maximum increments of 5,000 lbs. (2,500 kgs) and checked in a minimum of 3 increments. The system shall be checked through its entire weighing range to or above the maximum weight which is expected to be applied and shall be accurate within a tolerance of 0.5%.
   Surge bins that do not include a weighing system shall have platform truck scales meeting the requirements of **Section 109** mounted under the loading hopper.

8. Aggregate Feed.
   Aggregate shall be proportioned by feeding each size aggregate from a separate cold bin. The belt that delivers the aggregate shall have a load cell capable of registering the amount of flow from each individual bin on a readout in the control office; or the aggregate shall be proportioned by a linear system based on measured RPM of each feeder belt at a constant gate opening to feed aggregate at a predetermined rate that is set in the control office and which has a readout in the control office. The rate of feed as determined from the bin settings shall agree with the load cell on the collection belt

feeding the dryer within a tolerance of ±10%. In the event that the predetermined tolerance is exceeded, an alarm shall sound, and if corrections are not made within 60 seconds, the plant shall automatically shut down. The aggregate feed system shall employ computer controlled adjustments to automatically produce mix of the correct proportions over the entire range of production rates of the plant.

If the Engineer has previously calibrated and approved the plant for temporary manual operation, the plant may run for a period not to exceed 2 working days, or portions thereof, on manual in the event of a computer breakdown.

9. Electronic Data Retention.

   The computer system and automatic weighing system shall include means to retain all electronic data during electrical power failures.

10. Dryer-Drum Plants Prior to January 1983.

    Dryer-drum plants approved by the Department prior to January, 1983 which do not employ computer controlled adjustments may continue to be used.

407.05-Hauling Equipment. Trucks used for hauling bituminous mixtures shall have tight, clean, smooth metal beds which have been thinly coated with a minimum amount of paraffin oil, hydrated-lime solution or other approved material from the Department's QPL to prevent the mixture from adhering to the beds. Each truck shall be covered immediately after loading at the plant with a cover of canvas or other suitable material. The covers shall be of sufficient size to protect the mixture from the weather. The cover shall lap down along the sides and rear of the truck bed a minimum of 6 inches(150 millimeters) and be secured by tie downs at a maximum of 5 ft. (1.5 m) spacing along the sides and rear of the truck bed. When necessary, so that the mixture will be delivered on the road at the specified temperature, truck beds shall be insulated and covers shall be securely fastened. Each truck shall have a ¼ inch(604 mm) hole in the side of the bed for the purpose of inserting a thermometer.

407.06-Bituminous Pavers. Bituminous pavers shall be self-contained, power-propelled units provided with an activated screed, equipped to be heated, and capable of spreading and finishing courses of bituminous plant mix material in lane widths applicable to the specified typical section and thickness shown on the plans. All paver extensions shall be full assembly extensions, including activated and heated screeds, auger extensions and auger guards. When augers are extended, the maximum distance from the augers to the end plate shall be 18 in. (450 mm). Augers shall be within 4 ft. (1.2 m) of the end plate on trailing edge extendible screeds, however if bolt-on extensions are used the augers shall be extended a distance equal to the length of the bolt-on extensions. Strike off boxes shall not be permitted except on continuously varying width sections. Materials for shoulders less

than 8 ft. (2.4 m) in width and similar construction may be placed by means of approved mechanical spreading equipment.

The paver shall be equipped with a receiving hopper having a sufficient capacity for a uniform spreading operation. The hopper shall be equipped with a distribution system to place the mixture uniformly in front of the screed.

The screed or strike-off assembly shall produce effectively a finished surface of the required evenness and texture without tearing, shoving or gouging the mixture.

All asphalt paving machines shall be equipped with automatic grade and slope controls. Both the grade and slope controls shall be in working order at all times, except that, in the event of mechanical failure of the automatic controls, the Contractor will be permitted to finish the day's work using manual controls but will not be allowed to resume work the following day until both the grade and slope controls are in first class working order.

The Engineer may allow the Contractor to pave the inside shoulder concurrently with the inside traffic lane, subject to the approval of the price adjustment for the mix used on the shoulder and approval of the paving and rolling equipment by the Engineer. In addition to the preceding requirements, the paver must have an articulated screed that can be adjusted to fit the pavement cross section and a power unit capable of handling the increased loading without undue stress.

407.07-Rollers. Rollers shall be self-propelled and of steel-wheel, pneumatic tire, and/or vibratory type. Rollers shall be in good condition, capable of reversing without backlash and shall be operated at speeds slow enough to avoid displacement of the bituminous mixture. Rollers shall be equipped with a device for moistening and cleaning the wheels as required.

Additional requirements are:

1. The steel-wheel roller shall weigh a minimum of 8 tons(7.25 metric tons) and may be either a 3 wheel or tandem type.
2. The pneumatic tire rollers shall have a minimum contact pressure of 85 psi(585 kPa). The roller shall contain 2 axles upon which are mounted not less than 7 pneumatic-tire wheels in a manner so that the rear set of tires will not track the front set. The axles shall be mounted in a rigid frame provided with a loading platform or body suitable for ballast loading. The tires shall be uniformly inflated. The Contractor shall furnish to the Engineer charts or tabulations of the contact area and contact pressures for the full range of tire inflation pressures and loadings for each size of roller tire furnished. A combination roller (pneumatic and steel wheel combination), of the make and model approved by the Department, may be substituted for a pneumatic tire roller.
3. The use of vibratory rollers will be permitted when the particular roller proposed for use is approved by the Engineer.

The required rollers shall be on the job, inspected, and approved before paving operations are begun.

When the Contractor is paving the inside shoulder concurrently with the inside traffic lane, an additional roller a minimum of 4 ft. (1.2 m) wide to a maximum width of 1 ft. (300 mm) wider than the inside shoulder being paved, shall be required to compact the shoulder. Neither the roller(s) on the inside traffic lane nor the roller on the shoulder shall be allowed to traverse between the inside shoulder and the inside traffic lane.

407.08-Small Tools. The Contractor shall provide all necessary small tools and suitable means for keeping them clean and free from accumulations of bituminous materials.

CONSTRUCTION REQUIREMENTS

407.09-Weather Limitations. Bituminous plant mix may be placed on properly constructed and accepted subgrade or previously applied layers provided the following conditions are met:

1. The subgrade and the surface upon which the bituminous plant mix is placed shall be free of excessive moisture.

2. The bituminous plant mix shall be placed in accordance with the temperature limitations of the following table and only when weather conditions otherwise permit the pavement to be properly placed, compacted and finished.

TEMPERATURE LIMITATIONS

Compacted Thickness	Minimum Placement Temperature Air or Surface (Whichever is less) Degrees F(Degrees C)	
	Unmodified mixes	Modified Mixes
1.5 in. or less (40 mm)	45° F(7° C)	55° F(13° C)
> 1.5 in. (40 mm)	40° F(4° C)	50° F(10° C)

3. Unless otherwise permitted in writing, no bituminous plant mix, with a compacted thickness of 1.5 in. (40 mm) or less, shall be placed between November 30 and April 1; and further, no bituminous plant mix, with a compacted thickness greater than 1.5 in. (40 mm), shall be placed between December 15 and March 16. Where permission is granted to place mix during the above prohibited periods, the temperature requirements in paragraph 2 above shall be increased 10° F(6° C).

407.10-Conditioning of Existing Surface. When bituminous mixes are to be placed upon an existing concrete pavement, with or without a bituminous overlay, all excess bituminous material shall be removed from joints and cracks. Sections of existing pavement that are broken and pumping under traffic shall be removed. Pavement where blowups have occurred at joints or cracks shall be removed to provide a minimum opening of 1 ft. (300 mm) for the full width of the pavement.

When the bituminous mixture is to be placed upon an existing bituminous pavement, any areas containing excess bitumen and any failures in the existing surface and base shall be removed as directed by the Engineer.

The Contractor shall properly adjust all manholes and catch basin frames, associated with the storm sewer system, to the finished grades of the pavement. Unless otherwise specified, such adjustments shall be made without additional compensation. The respective Utility Owner(s) shall properly adjust all utility manholes, utility valve covers and like structures, to the finished grades of the pavement, unless otherwise stipulated by the Plans.

Unsatisfactory subgrade material encountered when existing pavement is removed shall be removed and replaced with approved material. Openings left by the pavement and base removal shall be filled to the full depth of the existing pavement, with the overlay mixture or other approved material, as directed by the Engineer; and compacted in layers not to exceed 3 in. (75 mm) in thickness.

Contact surface of curbing, gutters, manholes, and other structures shall be painted with a thin, uniform coating of bituminous material prior to the mixture being placed against them.

Existing surfaces that are warped and irregular shall be brought to uniform grade and cross section by the use of the leveling mixture specified under **Section 307**, when indicated on the Plans.

407.11-Preparation of Bituminous Material. The bituminous materials for hot mixes shall be heated to the required mixing temperature in accordance with the following **Table B**:

Table B

PG Binder Grade	Minimum Temp.	Maximum Temp.
PG 64-22, PG 67-22	290° F(143° C)	350° F(177° C)
PG 70-22	320° F(160° C)	350° F(177° C)
PG 76-22	320° F(160° C)	350° F(177° C)
PG82-22	325° F(163° C)	350° F(177° C)

The temperature for Grading AS and Grading ACRL mixtures shall be between 225 and 275° F(110 and 135° C), except when modified binders are used, and then the temperatures shall be in accordance with **Subsection 407.11**, Table B, above.

407.12-Preparation of Aggregates. Unless otherwise specified, the aggregate for hot mixes shall be dried and heated so as to produce a completed mix of a uniform temperature in accordance with **Subsection 407.11, Table B**. Flames used for drying and heating shall be properly adjusted to avoid damage to the aggregate and to avoid soot on the aggregate.

On all plants requiring screens, the hot dried aggregate shall be screened into 2 or more fractions as specified. The separated fractions shall then be conveyed into separate compartments ready for batching and mixing with bituminous material.

407.13-Mixing. The dried aggregates shall be combined within the mixer in the amount of each fraction of aggregates required to meet the job mix formula. The bituminous material shall be measured and introduced into the mixer in the amount specified by the job mix formula.

After the required amounts of aggregate and bituminous material have been introduced into the mixer, the materials shall be mixed until a complete and uniform coating of the particles and a thorough distribution of the bituminous material throughout the aggregate is secured. Wet-mixing time shall be determined by the Engineer for each plant and for each type of aggregate used, but in no case shall the wet-mixing time be less than 25 seconds for batch type plants and 40 seconds for continuous mix plants.

The temperature of the completed mixture, (determined at the time it is dumped from the mixer) made with aggregates containing absorbed moisture which causes foaming or boiling in the completed mix shall be not less than 225° F(110° C). The temperature of the mix when it is discharged from the mixer shall not deviate from that shown in **Subsection 407.11, table B.**

The temperature for Grading AS and Grading ACRL mixture shall be between 225 and 275° F(110 and 135° C).

Unless otherwise specified the temperature of all other bituminous pavement mixture shall be as designated in **Subsection 407.11, table B.**

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Hot-mixed bituminous mixtures may be placed in surge or storage silos provided that the mixture as used from the silos meets all the specification requirements for the particular mix involved.

When the use of surge or storage silos is permitted, the following additional requirements shall apply:

1. The surge bin or storage silo system shall conform to the requirements of **Subsection 407.04(a) 11**.
2. The storage silos or surge bins shall be emptied when directed by the Engineer in order to check material quantities.
3. Hours of plant operation, whether for storage or direct shipment to the road, shall be limited to reasonable working hours in order that normal inspection of plant operations may be performed.
4. Bituminous mixtures placed in a surge bin must be removed on the same day in which it is stored.
5. Bituminous mixtures Gradings A, AS, ACRL and B may be stored for up to 48 hours and Gradings BM, BM2, C, CS, CW, D, E and F for up to 96 hours in a storage silo provided the following requirements are met:
   (a) An approved silicone additive shall be added to the asphalt cement for mixes to be stored beyond the day of mixing.
   (b) The stored bituminous mixture shall be kept sealed at all times during storage.
   (c) The storage silo shall be filled to at least 90% of capacity.

6. Samples of the stored material will be taken following the period of storage.

7. Material stored will be subject to the temperature, segregation, and laying requirements as required for unstored plant production.
8. Excessive segregation, lumpiness, or stiffness of the mix shall be sufficient cause for rejection by the Engineer.
9. The Surge bins and Storage silos shall be located in a position that enables the top of the truckload to be visible to the load operator during the loading operation.

407.14-Spreading and Finishing. Unless otherwise specified or permitted, bituminous mixtures shall be delivered and spread on the roadway in ample time to secure thorough compaction during daylight hours unless otherwise directed by the Engineer. The temperature of the mixture at the time of depositing in the paver hopper shall be in accordance with **Subsection 407.11, Table B.**

The mixture shall be placed upon an approved surface, spread and struck off to the established line, grade and elevation by means of approved asphalt paving machine(s). Echelon or full-width paving may be permitted where plant production is capable of supplying the paver so that a constant forward speed can be maintained. Alignment of the outside edge of the pavement shall be controlled by preset control string lines. Where multi-course pavements are placed, the longitudinal joint in 1 layer shall offset that in the layer immediately before by approximately 1 ft. (300 mm); however, the joint in the top layer shall be at the center-line of the pavement if the roadway comprises 2 lanes of width, or at lane lines if the roadway is more than 2 lanes in width. The Contractor shall be required to pave in the direction of traffic.

A paving machine shall not be fed from more than 1 asphalt plant. Plant production and paving operations shall be so coordinated that there is constant forward movement of the pavers. Repetitive interruptions or stopping of the paver shall be cause for the Engineer to stop the work until the cause of the stoppage is corrected. If the paver must be stopped for a significant period of time, a joint shall be constructed and the paver moved from the roadway before the bituminous mixture has cooled sufficiently to prevent proper compaction. If the bituminous mixture is permitted to cool to the extent that the required density cannot be obtained, the mixture shall be removed and replaced at the Contractor's expense.

Unevenness of texture, segregation(including end-of-load segregation), as measured by a properly calibrated nuclear gauge, tearing or shoving of bituminous mixture that occurs during the paving operation, shall be reason to stop the paving until the condition is corrected. Unacceptable mix shall be immediately removed and replaced at the Contractor's expense. Excessive throwing back of the bituminous mixture will not be permitted.

Automatic screed controls utilizing either the string line, ski type grade reference system or a non-contact averaging system will be required on all work regardless of the paver width. The string line reference system may be required on new construction. In the event the base has been finished with equipment having automatic grade control or the Contractor demonstrates that an alternate method of spreading and finishing will result in a satisfactory riding surface the Engineer may conditionally waive the

string line requirement and authorize use of the ski type reference system. In any event the Engineer may at any time require the use of a string line reference system, even though it may have previously been waived, if in his opinion, the use of the string line will result in a superior riding surface. When the string line system is required on a multi-course pavement, it shall be used on at least 2 courses exclusive of the surface course. Where the ski type system is used, the ski shall have the maximum practical length and in no case shall it be less than 40 ft. (12 m) in length. Pavement lanes previously placed with automatic controls or to form grade may serve as longitudinal control reference for placing adjacent lanes by utilizing a ski or joint matching shoe.

The string line reference system shall consist of suitable wire or twine supported by approved devices that will be compatible with the type of automatic paver control system used. The string line and supports shall be capable of maintaining the line and grade designated by the Plans at the point of support while withstanding the tensioning necessary to prevent sag in excess of 1/4 in. (6 mm) between supports spaced 50 ft. (15 m) apart. Additional supports shall then be installed to provide a minimum spacing of 25 ft. (8 m), or less as directed by the Engineer, to remove the apparent deviation of the string line from theoretical grade.

The Contractor shall furnish all materials, equipment, labor, and incidentals required to construct the string line reference system as described herein and shall maintain same until its use is no longer required. The cost of erecting and maintaining the string line reference system shall be included in the unit price bid for other items of construction. The string line reference system shall be complete in place at least 300 ft(100 m) in advance of the point where the pavement is being placed. Automatic screed controls will not be required on sections of projects where service connections and other conditions interfere with their efficient operation.

On areas where irregularities or unavoidable obstacles make the use of mechanical spreading and finishing equipment impracticable, the mixture shall be taken from the hopper of the spreading machine and shall be distributed immediately into place by means of suitable shovels and other tools and spread with rakes and lutes in a uniformly loose layer of such depth as will result in a completed course having the required thickness.

The Contractor and the Department will each be required to have an individual that is certified by the Department through the HMA Roadway Certification Course.

407.15-Compaction. After the bituminous mixture has been spread, struck off, and surface irregularities adjusted, it shall be thoroughly compacted. The method employed must be approved by the Engineer and be capable of compacting the mixture to the specified density while it is in a workable condition. When no density requirements are specified, a system of compaction for roadway pavements shall be employed which has previously produced required bituminous pavement densities. A control strip and random density samples may be employed to aid the Engineer in evaluating the system.

In general, compaction shall be accomplished by the use of a combination of the equipment designated in **Subsection 407.07**. The

following are minimum roller requirements; however, the number of rollers shall be increased if the required results are not being obtained.

Except as noted below, each paving train shall consist of a minimum of 3 rollers as specified in **Section 407.07**. The intermediate roller in each train shall be a pneumatic type. If the surface course contains a latex or polymer additive, a steel wheel type roller for intermediate rolling may be used instead of a pneumatic type provided the surface course meets density requirements.

A minimum of 2 rollers will be required when placing 307 CS mix. Breakdown rolling shall be performed, as soon as possible and while the mixture is sufficiently hot, by a pneumatic tire roller having a minimum contact pressure of 85 psi (585 kPa). A combination roller may not be substituted for a pneumatic roller when placing CS mix. The paver speed shall be regulated so rollers can maintain proper compaction of the mixture as determined by the Engineer.

The minimum number of rollers listed above may, with the approval of the Engineer, be reduced to 1 roller of either the steel-wheel or vibratory type on the following types of construction; (a) On shoulder construction, (b) On incidental construction such as bridge approaches, driveways, etc., and (c) on projects containing less than 10,000 s.y. (9,000 m^2) of bituminous pavement.

Unless otherwise directed, rolling shall begin at the low side and proceed longitudinally parallel to the road centerline. When paving in echelon or abutting a previously placed lane, the longitudinal joint shall be rolled first, followed by the regular rolling procedure. When paving in echelon, rollers shall not compact within 6 in. (150 mm) of an edge where an adjacent lane is to be placed. Rollers shall move in a slow uniform speed with the drive wheels nearer the paver and shall be kept as nearly as possible in continuous operation. Rolling shall continue until all roller marks are eliminated. Rollers shall not park on the bituminous pavement.

To prevent adhesion of the mixture to the rollers, the wheels shall be kept properly moistened with water or water mixed with very small quantities of detergent or other approved material. An excess of liquid shall not be used.

Rollers shall not be refueled on the bituminous pavements.

Density Requirements.

ADT 1,000 or less

MIX TYPE	% OF MAXIMUM THEORETICAL DENSITY (AVERAGE)	NUMBER SINGLE TESTS LESS THAN, %
A	90	87
B, BM & BM2	90	87
C & CW	90	87

D	90	87
E	90	87

ADT 1,000 to 3,000

A	91	89
B, BM & BM2	91	89
C & CW	91	89
D	91	89
E	91	89

ADT 3,000 or greater

A	92	90
B, BM & BM2	92	90
C & CW	92	90
D	92	90
E	92	90

Any ADT

Shoulder Mix (D or E)	88	85
A S and A-CRL	None*	None
CS	None*	None

* Density requirements shall be waived on Bituminous Plant Mix Base Grading ACRL, Grading AS and Bituminous Plant Mix Leveling Course, Grading CS; however, a system of compaction for roadway pavements shall be employed which has been approved by the Engineer. When placing Bituminous Plant Mix Base Grading ACRL and Grading AS, the intermediate roller (pneumatic tire) specified previously may be replaced by a steel wheel type if irreparable damage to the pavement is occurring.

The density(bulk specific gravity) determination for a compacted asphalt mixture shall be performed in accordance with AASHTO T-166, Method A or C.

Any base or surface course that tests below the minimum density shall be corrected until the density of the area is equal to or above minimum before it can be used to determine the average density of the lot. No successive layer, where applicable, shall be placed until the area has been corrected. When it is necessary to determine the classification of open graded or dense graded mixes and to measure segregation, ASSHTO T-269 or ASTM D-3203 shall be used.

For density testing purposes, the pavement shall be divided into lots of 10,000 s.y.(9,000 m^2), except for 307 Gradings A, B and BM which shall

be divided into lots of approximately 5,000 s.y.(4,500 m^2). Five density tests shall be performed in each lot and the average results compared with the requirements listed above. At the beginning of the project or at any time it is deemed advisable, smaller lots may be considered in order to evaluate compaction methods or for other reasons which are approved and/or directed by the Engineer.

It is intended that acceptance density testing will be accomplished as soon as is practicable. If the average density of the lot does not conform to the requirements stated herein above, or if an individual test value does not meet the requirements stated herein above, the Contractor shall continue his compactive effort until the required density is obtained.

Along forms, curbs, headers, walls and other places not accessible to the rollers, the mixture shall be compacted thoroughly with hot hand tampers, smoothing irons, or with mechanical tampers. On depressed areas, a trench roller may be used to compact the mix.

Any defective mixture shall be repaired or replaced to the satisfaction of the Engineer.

Test Strips.

Test Strips shall be required for all A, B, BM, C, CW, D, E and F mixes to establish rolling patterns, to calibrate nuclear gauges, to verify that the base course or surface course meets the density requirements of the specifications, and for mix design/ production verification as required.

Construction of the test strip shall be as follows:

1. The base course or other pavement course upon which a test strip is constructed shall have been approved by the Engineer prior to the construction of the test strip.
2. Equipment proposed for use in the compaction of test strips, shall meet the requirements set forth in this subsection and **Subsection 407.07**.

The test strip shall be constructed at the beginning of work on the pavement course. New test strips shall be required when:

1. a change in the job mix formula is necessary
2. a change in the source of materials occurs
3. a change in the material from the same source is observed
4. There is reason to believe that the test strip density is not representative of the bituminous mixture being placed.

With the approval of the Engineer, the Contractor may be permitted to construct additional test strips.

Each test strip shall be constructed with approved bituminous mixture and shall remain in place as a section of the completed work. Each test strip shall be 1 paver width wide and have an area of at least 400 s.y. (350 m^2) and shall be of the depth specified for the pavement course concerned.

Compaction of the test strip shall commence immediately after placement of the bituminous mixture and be continuous and uniform over the entire test strip.

The compaction of the test strip shall be continued until no appreciable increase in density (1 lb/c.f.. (15 kgs/m^3)) as measured with the nuclear gauge can be obtained by additional roller coverage. The roller coverage necessary to obtain this maximum density shall be used as the rolling pattern for the remainder of the project. Cores shall be taken by the Contractor on the test strip at 10 randomly selected locations. Cores shall not be taken within 2 feet of the longitudinal edges for calibration or determining average densities. These cores shall be given to the State for use in calibrating the nuclear gauge and to verify that the average density of the test strip meets the density requirements of the specifications. All densities will be reported using the corrected nuclear gauge readings.

In the event the density of the asphaltic concrete in the test strip does not meet specification requirements, the Contractor shall make whatever changes are necessary to obtain the specified density. Other sources and combinations of aggregates shall be used as required, subject to approval of the Engineer, to produce a mix meeting the required density.

407.16-Joints. Placing of the bituminous paving shall be as continuous as possible. Rollers shall not pass over the unprotected end of a freshly laid mixture unless authorized by the Engineer. Transverse joints shall be formed by cutting back on the previous run to expose the full depth of the course. A brush coat of bituminous material shall be used on contact surfaces of transverse joints just before additional mixture is placed against the previously rolled material.

407.17-Pavement Samples. When directed, the Contractor shall cut samples from the compacted pavement for testing by the Engineer. Samples of the mixture shall be taken for the full depth of the course at locations selected by the Engineer. The samples shall be cut with a power saw or core drill and shall have a top surface area of at least 10 in^2(65 cm^2).

Holes formed by taking samples shall be filled with the same type mixture that was used to construct the course sampled, and compacted to conform to the surrounding pavement. Cutting samples and repairing sample holes shall be at the Contractor's expense.

407.18-Surface Requirements. The surface shall be tested with a 12 ft. (3.6 m) straightedge applied parallel to the centerline of the pavement. The deviation of the surface from the testing edge of the straightedge shall not exceed that specified for the respective types of bituminous construction under the applicable Subsections of these Specifications.

The transverse slopes of tilted pavements shall be tested with a string-line and string-level applied at right angles to the centerline of the pavement, and the per cent of slope, when computed for the full width of the pavement, shall not deviate more than 0.5 percentage points from that specified on the Plans.

The crown in crowned pavements shall be tested with a string-line applied at right angles to the centerline of the pavement and the crown shall not deviate more than 1/2 in. (13 mm) from that specified on the Plans.

Deviations greater than the specified tolerances shall be corrected by methods best suited for the purpose. Pavement that cannot be corrected to comply with the specified tolerances shall be removed and replaced at the Contractor's expense.

COMPENSATION

407.19-Method of Measurement. Chemical additives or modifiers, when required, will not be measured for payment, but will be considered as part of the asphalt cement.

Mineral filler will not be measured separately for payment, but will be included in mineral aggregates.

Asphalt cement and mineral aggregate, including mineral filler when required, will be measured by the ton(metric ton).

Where the mix is loaded from a storage or surge bin, the quantities will be determined by weighing the completed mix on truck scales meeting the requirements of **Section 109** and calculating the weight of asphalt cement and mineral aggregate based on the percentages measured into the mix by the appropriate scales or meters described in **Subsection 407.04**.

Where the mix is loaded directly into the hauling equipment from a batch plant, asphalt cement and mineral aggregate will be measured in batch quantities by scales or scales and meters as described in **Subsection 407.04(b).**

Where a continuous mix plant is used, Bituminous Material for Bituminous Plant Mix Pavement will be measured by the ton(metric ton) in accordance with the provisions of **Section 109**, Measurement and Payment. The Mineral Aggregate, including Mineral Filler when required will be determined by weighing the bituminous pavement mixture on truck scales meeting the requirements of **Section 109**, and deducting the weight of the bituminous material from the weight of total mixture accepted.

When the work described under **Subsection 407.10** is required, the removal and disposal of existing surface(concrete) will be measured by the yards.y. (m^2) in accordance with the provisions of **Section 109**, Measurement and Payment. Such measurement shall include the removal of bituminous overlay.

The Removal and Disposal of Existing Surface (Bituminous) will be measured by the s.y. (m^3) in accordance with the provisions of **Section 109**, Measurement and Payment. Such measurement shall include the removal of base material, except concrete, as directed by the Engineer.

Removal of unsatisfactory subgrade material where existing pavement has been removed will be measured by the c.y.(m^3) in accordance with the provisions of **Subsection 203.09**. Material used to replace such undercutting will be measured and paid for in accordance with the specification for the type of material used.

Bituminous mixtures used to fill openings left by pavement removal will be measured for payment in accordance with the provisions of this **Subsection 407.19**. Base materials used to fill openings left by base

removal will be measured as provided for in the respective Sections for each type specified.

Adjustment of catch basin grates and frames, water valve boxes, gas valve boxes and manhole covers and frames shall be measured per each when required.

407.20-Basis of Payment.

A. General:

All work performed and measured as prescribed above will be paid for as provided in the respective sections for each type specified.

B. Acceptance of the Mixture:

1. General:

The bituminous mixture will be accepted at the plant with respect to gradation and asphalt content, on a LOT basis. The material will be tested for acceptance in accordance with the provisions of **Subsection 407.03(D)** and the following requirements. However, any load or loads of mixture which, in the opinion of the Engineer, are unacceptable for reason of being excessively segregated, aggregates improperly coated, or of excessively high or low temperature shall be rejected for use in the work.

A standard size LOT at the asphalt plant shall consist of a day's production. The number of sublots in a LOT will vary from n=1 to n=4 according to the following:

Quantity	Number of Sublots
3,001-4,000 tons(metric tons)	4
2,001-3,000 tons(metric tons)	3
1,001-2,000 tons(metric tons)	2
less than 1,001 ton(metric tons)	1

When the total plan quantity of any mix is less than 1,000 tons(metric tons), the Department will accept the mix on the basis of visual inspection and Contractor Quality Control certification. The Department may run extraction, gradation analysis, or other tests deemed necessary for acceptance purposes.

2. Defective Materials:

(a) Acceptance or Rejection. Following the application of the appropriate acceptance plan, the decision of the Engineer shall be final as to the acceptance, rejection, or acceptance at an adjusted payment of the LOTs.

(b) Disposition of LOTs. Nonconforming LOTs of materials, products, or complete construction that are not adaptable to correction by reworking shall be removed and replaced at the Contractor's expense or accepted at an adjusted payment as

stated in these Specifications, or if not stated, as directed by the Engineer.

When a deficiency is determined, the applicable payment as shown in these Specifications will be applied to the entire LOT. When multiple deficiencies occur, the applicable partial payments will be applied to the LOT of material that is identified by each deficiency. The payment adjustment for each deficiency will be applied separately and will not be affected by any other payment adjustment occurring for the same LOT except that when there are 2 or more deficiencies in the gradation acceptance tests, only the greater payment adjustment will be applied. When an area or linear measurement is used to specify lot size, the equivalent tons(metric tons) of mix placed in each lot shall be determined by using the average calculated spread from the plant inspector's daily report for that days production.

3. Acceptance of the mixture shall be on the basis of test results on consecutive random samples from each LOT. One random sample shall be taken from each sublot. The bituminous mixture will be sampled at the plant in accordance with AASHTO T-168. The percent bitumen content of the mixture will be determined in accordance with AASHTO T-164 or by AASHTO T-308 except as herein revised.

   The Contractor may, at his option, use an approved ignition furnace in lieu of a vacuum extractor for the use in determining asphalt content and gradation. The method of calibration and test procedures shall be in compliance with AASHTO T-308 with the following provisions:

   (a.) Only AASHTO T-308 Method A shall be used.
   (b.) When calculating the washed gradation of the aggregate by AASHTO T-30, the total aggregate mass used shall be the total of the recovered aggregate after ignition and the amount of aggregate lost in the furnace. Use the following formula:

$$\text{Total Aggr Mass} = \text{Recovered Aggregate Mass} + \text{Original} \frac{\text{Mix Sample Mass} \times \text{Calib. Factor}}{100}$$

   (c.) When using a mixture containing RAP, assume a zero correction factor for the RAP. Burn off a minimum of 3 samples of RAP to determine the binder content of the RAP. Blend the virgin aggregate with the RAP, and then add the virgin AC to the prescribed mass for the required AC Content. Calculate the calibration factor by subtracting the known AC

Content of the mixture from the measured AC Content on the furnace ticket.

At least once per week, per mixture, during production, the correction factor shall be checked with a sample of the aggregate mixture proportions, blended at the optimum asphalt content. The correction factor shall be adjusted accordingly. The contractor shall keep records of all correction factors for all mixtures. Adjusted payment for asphalt content and gradation will be based on the ignition furnace results in accordance with **Subsection 407.20(Table 407-2).** It is understood that use of this alternative equipment will be at no additional cost to the Department.

The percents passing the sieves will be determined in accordance with AASHTO T-30.

TABLE 407-2

ACCEPTANCE SCHEDULE OF PAYMENT
(Asphalt Plant Mix Characteristics)

Characteristics	**Pay Factor**	**Average Arithmetic Deviation of the Lot Acceptance Test from the Job Mix Formula**	
		1 Test	2 Tests or more
Asphalt Cement	1.00	0.00-0.40	0.00-0.35
Content ***	0.95	0.41-0.46	0.36-0.40
(Extraction or	0.90	0.47-0.52	0.41-0.45
ignition oven)	0.80*	over 0.52	over 0.45
Gradation			
3/8 In.	1.00	0.00-6.50	0.00-5.70
(9.5 mm),	0.95	6.51-7.08	5.71-6.20
Sieve and	0.90	7.09-7.66	6.21-6.69
Larger	0.80*	over 7.66	over 6.69
Gradation			
No. 4 Sieve**	1.00	0.00-4.62	0.00-4.00
(4.75 mm)	0.95	4.63-5.20	4.01-4.50
	0.90	5.21-5.77	4.51-5.00
	0.80*	over 5.77	over 5.00
Gradation			
No. 8 16, 30 & 50	1.00	0.00-3.80	0.00-3.30
(2.36 mm, 600 µm	0.95	3.81-4.46	3.31-3.91
& 300 µm ,) Svs**	0.90	4.47-5.12	3.92-4.52
	0.80*	over 5.12	over 4.52

Gradation			
No. 100 & 200	1.00	0.00-1.80	0.00-1.60
(150 µm & 75 µm)	0.90	2.01-2.20	1.76-1.90
Sieves**	0.95	1.81-2.00	1.61-1.75
	0.80*	over 2.20	over 1.90

*If approved by the Engineer, the Contractor may accept the indicated partial pay. The Department may require removal and replacement at no cost. The Contractor has the option to remove and replace at no cost to the Department at any time.
**When there is more than 1 reduced payment relating to gradation in 1 LOT of material, only the greatest reduction in payment will be applied. Reductions applicable for any other reason will be cumulative.
***Does not apply to 307 Grading A, AS, or ACRL mixes.

Deduction for both asphalt content and gradation deficiencies shall be cumulative. The deduction shall be applied to the total price of the mix(asphalt cement and aggregate combined) and shall be made under the item for Asphalt Cement Content and Gradation Deduction.

4. Additional Tests:

The Engineer may perform any test at any time to determine the effectiveness of the Contractor's quality control.

5. Acceptance for Mix Density on the Roadway:

A deduction in payment, not as a penalty but as liquidated damages, shall be made for failure to meet the density requirements as outlined in **Subsection 407.15**. As soon as practical after the final rolling is completed on each lot, 5 density tests shall be performed by the Department at locations determined by the Engineer, and an average of all such tests shall be computed. Any deduction for failure to meet density requirements shall be computed to the nearest 0.1% as a percentage of the total payment otherwise due for each lot. The percent of total payment to be deducted shall be 5 times the percent the average in-place density for each lot that fails to meet the requirements of **Subsection 407.15**. Any deduction in monies due the Contractor for failure to meet the Density Requirements shall be made under the item for Density Deduction.

SECTION 411-ASPHALTIC CONCRETE SURFACE (HOT MIX)

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SECTION 411-ASPHALTIC CONCRETE SURFACE (HOT MIX)

411.01-Description. This work shall consist of an asphaltic concrete pavement composed of a mixture of coarse aggregate, fine aggregate, mineral filler if specified or required, and asphalt cement, constructed on a prepared roadbed in accordance with these Specifications and in reasonably close conformity with the lines, grades, typical cross section and rate of application shown on the Plans, or established by the Engineer.

The provisions of **Section 407** of these Specifications shall apply to this construction unless otherwise stipulated.

MATERIALS

411.02-Materials. Materials used in this construction shall meet the requirements of the following Subsections of these Specifications:

Material	Subsection
Mineral Aggregate	**903.11**
Asphalt Cement, PG 64-22, 70-22, 76-22 or 82-22	**904.01**
Mineral Filler	**903.16**
Chemical Additive	**918.09(B)**

The mineral aggregate, bituminous material and plant mix will be accepted as provided for in **Subsection 407.02**.

411.03-Composition of Mixtures.

(a) General Composition of mixtures used in this construction shall meet all applicable requirements of **Subsection 407.03**.

(b) The specified mineral aggregate and asphalt cement shall be combined in such proportions as to produce mixtures within the following master composition limits.

Proportions of Total Mixture, Per Cent by Weight

Surface Courses	Effective Combined Mineral Aggregate	Asphalt Cement
Grading D	93.0-94.7	5.3-7.0*
Grading E	93.0-94.7	5.3-7.0*
Grading E (shoulders)	92.0-94.7	5.3-8.0*

*If the effective combined specific gravity of the aggregate exceeds 2.80, the above proportions may be adjusted as directed by the Engineer. The upper limit for Flow values shall not apply to mixes with modified asphalt liquids.

Grading D

In addition to the other requirements of these specifications the composition of the mineral aggregate shall be such that when combined with the required amount of bitumen the resultant mixture shall have:

All Roads

Mix	Stabil. Min. lbft* (kN)	Flow 0.01 in. (mm) ***	Design Void content %*	Production Void Content %*	Min. VMA %*	Dust-Asphalt Ratio**
411D	2,000 (9.0)	8-16 (2-4)	4.0±0.2	3-5.5	14	0.6-1.2

*Tested in accordance with AASHTO T 245 with 75 blows of the hammer on each side of the test specimen, using a Marshall Mechanical Compactor.

**The dust to asphalt ratio is the percent of the total aggregate sample that passes the 200 mesh(75 µm) sieve as determined by AASHTO T 11 divided by the percent asphalt in the total mix

***Flow will only be required when using a non-modified binder (PG 64-22 or 67-22)

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

The addition of limestone screenings or agricultural limestone in a maximum amount of 25% by weight of the mineral aggregate may be required to comply with this section. When crushed stone screenings meeting the requirements of **Subsection 903.11 (c)** are used, all additional fines shall be natural or manufactured sand. When natural sand is used as fine aggregate, it shall be limited to a maximum amount of 25% by weight of the mineral aggregate. A maximum of 5% mineral filler meeting the requirements of **Subsection 903.16** may be substituted for an equal quantity of the limestone fines. If the mixture does not comply with the design criteria, another source of aggregate shall be required.

When gravel is used as the coarse aggregate for a 411 Grading D mix, a minimum of 20% by weight limestone screenings, agricultural limestone and/or mineral filler shall be required.

Grading E

In addition to the other requirements of these specifications where Grading E is used for the riding surface the composition of the mineral aggregate shall be such that when combined with the required amount of bitumen the resultant mixture shall have:

High Volume Roads (ADT over 1,000)

Mix	Stability Min. lbft* (kN)	Flow 0.01in. (mm) **	Design Void content %*	Production Void Content %*	Min. % VMA*
411E	2,000 (9.0)	8-16 (2-4)	4.0±0.2	3-5.5	14

Low Volume Roads (ADT 1,000 and below) and shoulders

Mix	Stability Min. lbft* (kN)	Flow 0.01in. (mm)**	Design Void content%*	Production Void Content %*
411E	1,500 (6.75)	8-16 (2-4)	3.5±0.5	2-5

*Tested in accordance with AASHTO T 245 with 75 blows of the hammer on each side of the test specimen, using a Marshall Mechanical Compactor.

**Flow will only be required when using a non-modified binder (PG 64-22 or 67-22)

If the design criteria above cannot be obtained with the aggregate, submitted to the laboratory for design, another source of aggregate will be necessary.

(c) Recycled Asphalt Pavement

The Contractor may utilize asphalt pavement that has been removed from a Department project or other State Highway Agency project by cold planing or other approved means in combination with appropriate aggregate, asphalt cement and anti-stripping additive if required, to produce a mixture which will otherwise meet all the requirements of **Subsection 903.11** and the requirements herein **Section 411**. RAP shall be allowed in each mix listed in the following table:

Mix Type**	%RAP (Non-processed)**	%RAP (Processed)**	Maximum Particle size
411D(PG64-22, PG67-22)	0	15	½ in. (12.5 mm)
411D(PG70-22)	0	10	½ in. (12.5 mm)
411D(PG76-22, PG82-22)	0	10	½ in. (12.5 mm)
411E(Roadway)	0	25	½ in. (12.5 mm)
411E(Shoulder)	15	25	½ in. (12.5 mm)

*RAP that has been crushed and screened or otherwise sized such that the maximum recycled material particle size is less than that listed in the table above prior to entering the dryer drum, shall qualify as "Processed". "Non processed" RAP shall be similar material that has not been crushed and screened or otherwise sized previous to its use.

**All mixes shall contain at least 80% virgin asphalt except for 411E Shoulder Mix which shall have at least 65% virgin asphalt.

The grade of asphalt cement shall be as shown on the plans. The mixture will be accepted for aggregate gradation and asphalt content based on extractions or AASHTO T 308.

The Contractor will be responsible for his own sampling and testing of the RAP as well as new materials for bid purposes, and for the submission of the job mix formula in accordance with **Subsection 407.03**. After mixing, the moisture content of the total mix shall be no more than 0.1% as determined by oven drying, and the provisions for lowering the temperature because of boiling or foaming shall not apply.

The stockpile gradation tolerance for all recycled material on each sieve is listed below.

3/8in. (9.50 mm) sieve and larger .....± 10%
No. 4(4.75 mm) sieve.....± 8%
No. 8(2.36 mm) sieve.....± 6%
No. 30(600 µm) sieve.....± 5%
No. 200(75 µm) sieve.....± 4%

The mixture will be accepted for aggregate gradation and asphalt content based on extractions or in accordance with AASHTO T 308

(d) Anti-Strip Additive - Asphaltic concrete surface mixtures (Grading D & E) shall be checked for stripping by the Ten Minute Boil test for dosage rate and ASTM D 4867(Root-Tunnecliff procedure) for moisture susceptibility.

If moisture susceptibility is indicated, then an approved anti-strip agent shall be mixed with the asphalt cement at the dosage recommended by the respective test and as specified in **Subsection 918.09(B).**

EQUIPMENT

411.04-Equipment. The equipment used in this construction shall meet the requirements of **Subsection 407.04** through **407.08**. All equipment necessary for the satisfactory performance of this construction shall be on the project, and approved, before work will be permitted to begin.

The equipment for the construction of shoulder mixes with recycled material shall comply with **Section 407**, except that the asphalt plant shall be modified as approved by the Engineer to accommodate the asphalt planings which are to be added. If a batch plant is used to produce recycled mix, the aggregate shall be heated to a temperature that will transfer sufficient heat to the cold planings to produce a mix of uniform temperature within the specified range.

CONSTRUCTION REQUIREMENTS

411.05-General Requirements. The construction requirements for this work shall be as prescribed in **Subsections 407.09, 407.11, 407.12**, and **407.14** through **407.17** and the following Subsections.

411.06-Preparing the Designated Surface. Preparation of the designated surface upon which the material is to be placed shall be performed in accordance with the applicable provisions of **Subsection 404.05** of these Specifications.

Loops used for traffic signals shall be installed before the final surface is applied.

411.07-Mixing. Requirements for mixing shall be as prescribed in **Subsection 407.13**. In addition, the mixing cycle for surface course mixtures may require a dry-mixing period.

411.08-Surface Requirements. The surface shall meet the requirements specified under **Subsection 407.18**, and when tested in accordance with the provisions of that Subsection, the deviation of the surface from the testing edge of the straightedge shall not exceed 1/4 in. (6 mm).

COMPENSATION

411.09-Method of Measurement. Mineral Aggregate including Mineral Filler when required, and Asphalt Cement for Asphaltic Concrete Surface (Hot Mix) will be measured as prescribed in **Subsection 407.19**. Mineral Filler when required will not be measured for payment separately, but will be included as mineral aggregate.

If recycled mix is permitted, the completed mix, including new mineral aggregate, planings, asphalt cement and additive, shall be measured by the ton (tonne) in accordance with **Section 109**. For bidding purposes, the asphalt cement content of the specified mix shall be used in the chart below:

Mix Type	Asphalt Content
411-D	5.9%
411-E Roadway	6.3%
411-E Shoulder	6.3%

In the event that the Engineer sets an asphalt content other than that stated above, a price adjustment will be made based on the asphalt content set by the Engineer and the invoice price of the asphalt cement F.O.B. the asphalt plant. The price adjustment will be calculated according to the following formula:

PA =[IP x (DA-BA) x T]/100

Where:
PA = Price Adjustment
IP = Invoice price of asphalt cement
DA = Percent asphalt set on the mix design
BA = Percent asphalt specified above to be used for bidding
T = Total tons(metric tons) asphalt mix for price adjustment

The liquid anti-strip additive will be measured by the gallon(liter) and paid as outlined in **Subsection 411.10**. Hydrated Lime will be measured by the ton(metric ton) and paid as outlined in **Subsection 411.10**.

No direct payment will be made for polymer or latex additives and cost thereof shall be included in the price bid for the modified asphalt cement or modified mixture.

411.10-Basis of Payment. The accepted quantities of Asphaltic Concrete Surface (Hot Mix) or asphaltic Concrete Surface(Hot Mix) (Shoulders) with or without recycled material, complete in place, will be paid for at the contract unit price per ton(metric ton) of the total mix, which will include mineral aggregate, planings, asphalt cement and additives except anti-striping agent Payment will be made to the Contractor for additional asphalt cement as provided for above at the purchase price F.O.B. the asphalt mixing plant, as verified by invoice, and no

compensation will be allowed for further handling or processing. The Department will be reimbursed from monies due the Contractor for a decrease in asphalt cement content in the amount equal to the purchase price F.O.B. the asphalt plant.

The liquid anti-strip additive will be paid for based on certified invoices of material cost not to exceed $15 per gallon($4 per liter). Hydrated Lime anti-strip additive will be paid for based on certified invoices of material cost not to exceed $90 per ton($100 per metric ton). This payment shall be full compensation for all labor, materials, equipment and other incidentals incurred in utilizing the anti-strip additive.

In cases where the effective combined specific gravity of the mineral aggregate exceeds 2.80, the tonnage of mineral aggregate, or plant produced mixture, will be adjusted for payment by multiplying the tonnage of mineral aggregate, or plant produced mixture, used by a specific gravity of 2.80 and dividing by the higher specific gravity.

The work required to prepare the designated surface as provided for under **Subsection 411.06** will be measured and paid for in accordance with the provisions of the applicable Sections or Subsections under which the work is performed.

When the approved job mix formula includes a mixture of limestone with gravel, granite, slag, quartzite or gneiss, tests for the percent loss on ignition of the limestone aggregate in the asphalt paving mix shall be performed according to the provisions of **Subsection 407.03**.

In the event the percent of loss on ignition in the aggregate differs by more than ±2% from the loss on ignition indicated in the job mix formula, a deduction in payment in the price bid for the mix shall be made, not as a penalty but as liquidated damages. The percent of total payment to be deducted shall be 5 times the percent that the loss on ignition exceeds the job mix formula tolerance of ±2%.

All mix produced with aggregate tested and found to have a loss on ignition that differs more than ±6% from the loss on ignition indicated in the job mix formula shall be replaced or overlaid at the expense of the Contractor.

For the purpose of determining the deduction, lots of approximately 5,000s.y.(4,500 m^2) will be used. The sampling and testing to establish the loss on ignition will be performed in accordance with the Department's sampling and testing procedures. In event the initial tests indicates a variation in the loss on ignition of greater than ±2% than the value shown on the mix design, the additional sampling necessary to establish the loss on ignition of the aggregate in each lot shall be performed by the Contractor with the cost of the sampling being included in the contract unit prices bid for the paving items.

Any deduction for excess variation in loss on ignition shall be made under the item for material variation(deduction).

SECTION 903-AGGREGATES

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The Contractor shall establish a gradation for each aggregate used in the mix. The aggregate stockpile gradation tolerance on each sieve is listed below.

3/8 in. (9.5 mm) sieve and larger	± 10%
No. 4 (4.75 mm) sieve	± 7%
No. 8 (2.36 mm) sieve	± 5%
No. 30 (600 µm) sieve	± 4%
No. 200 (75 µm) sieve (coarse aggregate)	± 2%
No. 200 (75 µm) sieve (fine aggregate)	± 4%

When the coarse aggregate portion of Grading CW mix is crushed limestone, not less than 20% nor more than 50% by weight shall be natural sand, or sand manufactured from slag or other approved non-skid aggregate. When the coarse aggregate portion is crushed gravel or crushed slag, not less than 15 nor more than 40% by weight of the mineral aggregate shall be agricultural limestone or Size No. 10 limestone screenings.

The gradations of the coarse and fine fractions of aggregate shall be such that when combined in proper proportions the resultant mixture will meet one of the following gradings, as specified:

HOT PLANT MIX BASE COURSE
MIXTURE DESIGN RANGE OF GRADATIONS

	Total Per Cent Passing, by Weight			
Sieve Size	**Grading A**	**Grading AS**	**Grading ACRL**	**Grading B**
2 in. (50 mm)	100	100	100	100
1-1/2 in. (37.5 mm)	81-100	75-100	80-93	95-100
¾ in. (19 mm)	50-71	55-80	60-75	70-85
3/8 in. (9.5 mm)	35-50	-	-	49-72
No. 4 (4.75 mm)	24-36	7-11	12-16	34-51
No. 8 (2.36 mm)	13-27	-	-	23-42
No. 30 (600 µm)	7-17	-	-	11-22
No. 50 (300 µm)	-	-	-	9-14
No. 100 (150 µm)	0-10	0-6	0-4	4-10
No. 200 (75 µm)	0-4.5	0-4.5	0-3.5	2.5-6.5

HOT PLANT MIX LEVELING COURSE
MIXTURE DESIGN RANGE OF GRADATIONS

Total Per Cent Passing, by Weight

Sieve Size	**Grading BM**	**Grading BM2***	**Grading C**	**Grading CW**	**Grading CS**
1-1/4 in. (31.75mm)	-	100	-	-	-
1 in. (25 mm)	100	-	-	-	-
¾ in. (19 mm)	85-100	81-93	100	100	-
3/8 in. (9.5 mm)	59-79	57-73	70-90	75-100	100
No. 4 (4.75 mm)	42-61	40-56	39-66	-	89-94
No. 8 (2.36 mm)	29-47	28-43	23-47	43-67	53-77
No. 30 (600 µm)	13-27	13-25	10-27	23-47	23-42
No. 50 (300 µm)	7-20	9-19	8-15	-	-
No. 100 (150 µm)	4-10	6-10	4-8	4-10	9-18
No. 200 (75 µm)	0-6.5	2.5-6.5	2.5-6.5	2.5-6.5	6-13.5

*When natural sand is used as fine aggregate, it shall be limited to a maximum amount of 20% by weight of the mineral aggregate.

Asphalt treated permeable base gradation shall be as follows:

Sieve Size	Total percent passing by weight
2 in.(50 mm)	100
1-1/2 in.(37.5 mm)	70-100
¾ in.(19 mm)	55-80
No. 4(4.75 mm)	0-11
No. 100(150 µm)	0-4
No. 200(75 µm)	0-3

903.07-Aggregate for Bituminous Coated Aggregate Base (Plant Mix). The mix aggregate for Bituminous Coated Aggregate Base shall be crushed stone or crushed slag meeting the quality requirements of ASTM D 692,

requirements as the mix aggregate and shall meet the gradation requirements of Size No. 8, **Subsection 903.22**.

903.11-Aggregate for Asphaltic Concrete Surface Courses (Hot Mix). Aggregate for asphaltic concrete surface courses shall consist of a combination of coarse and fine aggregate, and mineral filler when required or specified. A minimum of three sizes of aggregates shall be required for all mix designs.

The Contractor shall submit a mix design at least 14 working days prior to the scheduled start of production of any asphalt paving mixture in complete accordance with **Subsection 407.03(C).**

If at any time the sources of materials are changed, a new mix design will be required in accordance with **Subsection 407.03(C)2**, Revision of Job Mix Formula.

(a) Coarse Aggregate.

The coarse aggregate(aggregate retained on the No. 4(4.75 mm) sieve) shall consist of crushed stone, crushed slag, crushed gravel, crushed granite, crushed quartzite, crushed gneiss, other approved non-skid aggregates or combinations thereof. The coarse aggregate shall meet the quality requirements of ASTM D 692 with the following exceptions and additions:

(1) All aggregate shall have a sodium sulfate soundness loss not exceeding 9%.
(2) Material retained on the No. 4(4.75 mm) sieve shall contain a maximum of 20% elongated pieces (length greater than 5 times the average thickness).
(3) Combined aggregate shall consist of siliceous particles processed from washed material, of which at least seventy per cent by count, of the material retained on the No. 4(4.75 mm) sieve shall have a minimum of 2 fractured faces, 1 of which must be fractured for the approximate average diameter or thickness of the particle. The addition of pea gravel or uncrushed particles will not be permitted. The absorption of the crushed combined aggregate retained on the No. 4(4.75 mm) sieve shall not exceed 5% when tested in accordance with AASHTO T 85.
(4) 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.
(5) After drying in the plant, the aggregate retained on the No. 4(4.75 mm) sieve shall have a loss of not more than 1% by weight when washed over a No. 8(2.36 mm) sieve in accordance with the coating test in **Subsection 407.03**.

(b) Fine Aggregate.

The fine aggregate (passing the No. 4(4.75 mm) sieve) shall consist of natural sand, fines prepared from stone, slag, gravel,

granite, quartzite, gneiss, other approved non-skid aggregates, or combinations thereof. It shall consist of hard tough grains free from injurious amounts of clay, loam or other deleterious substances. The fine aggregate when subjected to 5 cycles of Sodium Sulfate Soundness test shall have a weighted loss of not more than 12%. Manufactured sand shall have no more than five percent passing the No. 200(75 µm) sieve when tested in accordance with AASHTO T 11. Fine aggregate or screenings containing Calcium Sulfate ($CaSO_4$/gypsum) will not be allowed if more than 5% of the material passing the No.8(2.36 mm) sieve is chemically composed of Sulfur Trioxide (SO_3)

(1) Natural sand shall be washed. The natural sand shall be so graded that not more than 5% will be retained on the No. 4(4.75 mm) sieve.

(2) Fine aggregate consisting of natural sand will be tested in accordance with AASHTO T 11 and the amount of material finer than a No. 200(75 µm) mesh sieve shall not exceed 4% by weight.

The amount of deleterious substances in natural sand shall not exceed the following limits:

	Maximum Permissible Limits Percent by Weight
1. Clay Lumps	0.5
2. Coal & Lignite	0.5
3. Other deleterious substances (such as shale, alkali, mica, coated grains, soft & flaky particles)	3.0

(3) Agricultural limestone, when used as a portion of the fine aggregate, shall be manufactured from sound, durable stone and shall be crushed so that at least 85% will pass the No. 8(2.36 mm) mesh sieve and at least 50% will pass the No. 30(600 µm) mesh sieve.

(c) The Combined Grading.

The several aggregate fractions shall be sized, graded, and combined in such proportions that the resulting composite blend will meet 1 of the following grading requirements, as specified, together with the stipulations pertaining to the constituents of the blend hereinafter specified.

The Contractor shall establish a single value for each sieve size required in the mix for each aggregate stockpile with an

allowable stockpile tolerance on each sieve as specified in **Subsection 903.06(c).**

When Gradings D, E, or F are used for the surfacing of shoulders or for other non traffic lane construction, the design may be modified as approved by the Engineer.

ASPHALT CONCRETE SURFACE COURSE
MIXTURE DESIGNATION
DESIGN RANGE OF GRADATIONS

Total Percent Passing, by Weight

Sieve Size	Grading D	Grading E	Grading F
¾ in.) (19 mm	-	-	-
5/8 in. (16 mm)	100	100	-
½ in. (12.5 mm)	95-100	95-100	-
3/8 in. (9.5 mm)	80-93	80-93	100
No. 4 (4.75 mm)	54-76	54-76	89-100
No. 8 (2.36 mm)	35-57	35-57	78-92
No. 30 (600 µm)	17-29	17-29	38-67
No. 50 (300 µm)	10-18	10-18	23-47
No. 100 (150 µm)	3-10	3-11	7-18
No. 200 (75 µm)	0-6.5	0-8	5-13

When crushed gravel is used in Grading G mix, the percent passing the No. 100(150 µm) sieve shall be 2-7.

Grading D.

The coarse aggregate shall consist of crushed gravel, crushed granite, crushed slag, crushed quartzite or crushed gneiss. Other crushed aggregate may be used provided it has the following chemical, physical, and performance characteristics for Type I, Type II, Type III or Type IV aggregate:

(1) Type I
Silica Dioxide content - minimum of 40% (ASTM C-25)
Calcium carbonate content - maximum of 32%

The coarse aggregate shall contain a minimum of 50% by weight of acid insolubles that are coarser than the No. 100(150 µm) mesh sieve when tested in accordance with ASTM D 3042.

The British Pendulum (Tester) number BPN shall not be less than 30 when tested in accordance with AASHTO T 278 after nine hours of accelerated polishing of the aggregate using the British Wheel in accordance with AASHTO T 279.

(2) Type II

Silica Dioxide content - minimum of 30% (ASTM C-25)

The coarse aggregate shall contain a minimum of 35% by weight of acid insolubles that are coarser than the No. 100(150 µm) mesh sieve when tested in accordance with ASTM D 3042.

The British Pendulum (Tester) number BPN shall not be less than 30 when tested in accordance with AASHTO T 278 after nine hours of accelerated polishing of the aggregate using the British Wheel in accordance with AASHTO T 279.

In addition to the above requirements, the aggregate shall have met the preapproval process of the Division of Materials and Tests.

(3) Type III (for roads with current ADT of 15,000 or less excluding Interstate Highways).

Silica Dioxide content - minimum of 20% (ASTM C-25)

The coarse aggregate shall contain a minimum of 25% by weight of acid insolubles that are coarser than the No. 100(150 µm) mesh sieve when tested in accordance with ASTM D-3042.

The British Pendulum (Tester) number BPN shall not be less than 25 when tested in accordance with AASHTO T 278 after 9 hours of accelerated polishing of the aggregate using the British Wheel in accordance with AASHTO T-279.

In addition to the above requirements, the aggregate shall have met the preapproval process of the Division of Materials and Tests.

(4) Type IV (for 2 lane roads with a current ADT of 5,000 or less

Silica Dioxide content – minimum of 10% (ASTM C-25)

The British Pendulum(Tester) number shall not be less than 22 when tested in accordance with AASHTO T 278 after 9 hours of accelerated polishing of the aggregate using the British Wheel in accordance with AASHTO T 279.

The coarse aggregate must have a minimum Tennessee Terminal Texture Condition (TTTCM) value of 42.5 when tested in accordance with the method developed by the Tennessee Technological University.

In addition to the above requirements, the aggregate shall have met the pre-approval process of the Division of Materials and

Tests. The aggregate must also maintain a satisfactory level of field performance to remain an approved source.

The material shall be processed and stockpiled as an independent and separate operation. Each stockpile will be sampled and tested for approval prior to use.

The fine aggregate shall consist of natural sand or sand manufactured from gravel, slag or from crushed stone aggregate meeting the physical and chemical requirements listed above. The use of carbonate rocks such as limestone and dolomite or other aggregates tending to polish under traffic will not be permitted in the coarse aggregate and will be permitted only to the extent specified herein in the fine aggregate.

Grading E.

When Grading E is to be used as a surface for traffic lanes, the mineral aggregate shall be composed of not less than 50%, nor more than 80 percent crushed limestone, and not more than 50%or not less than 20% natural sand, slag sand, sand manufactured from gravel or other approved non-skid aggregates, or any combination of these materials, except as herein specified.

The sand percentage on the job mix formula shall be in the range of 20- to 50%. However, if needed to meet or improve the specified design criteria, the limestone and sand percentage may be altered by the numerical value of 5% from the percentage shown by the Contractor on the original job mix formula. If the aggregate percentages shown on the original job mix formula are altered, the Contractor shall submit a new job mix formula using the aggregate percentages shown on the Design.

When Grading "E" is used for surfacing of shoulders or other non-traffic lane construction, the mineral aggregate may be composed entirely of limestone including Size No. 10 (Screenings) and manufactured sand, but in no case shall the mineral aggregate for this construction consist of less than 50% limestone.

Grading F.

The mineral aggregate shall be composed of not less than 75% nor more than 85% of either natural sand, slag sand, sand manufactured from other approved non-skid aggregates, sand manufactured from siliceous materials or any combinations of these materials, and not less than 15% nor more than 25% of stone screenings meeting the gradation requirements of Size No. 10 **903.22**. Agricultural limestone meeting the requirements of **Subsection 903.11(b)** may be substituted for all or part of the stone screenings.

903.12-Aggregate for Slurry Seal and Micro-Surface.

(a) Aggregate for Slurry Seal. The aggregate shall be crushed slag, crushed granite or crushed stone (crushed stone as specified for the types listed for Grading D in **Subsection 903.11(c)**) meeting the requirements of ASTM D 692, except the gradation shall be as specified below. The aggregate shall have a minimum sand

SECTION 904-BITUMINOUS MATERIALS

904.01-Asphalt Cements.

Asphalt cement used on TDOT projects shall only be from Certified Asphalt Suppliers that have an approved Quality Control Plan in accordance with TDOT Standard Operating Procedures.

Asphalt cement shall conform to the requirements of AASHTO M 320 and in accordance with TDOT procedures. The solubility of base asphalt cement as required in AASHTO M 320 must be reported for information every 3 months in the suppliers' quality control program. In lieu of PG 64-22 when specified, asphalt cement graded to PG 67-22 may be used. PG 67-22 shall conform to the requirements of AASHTO M 320 when all applicable tests are conducted at 67° C and -12° C, and the dynamic shear of the rolling thin film, pressure aged vessel sample shall be tested at 26.5° C.

Modification of the asphalt shall be accomplished by properly blending styrene butadiene (SB), styrene butadiene styrene(SBS) or styrene butadiene rubber(SBR) to a PG 64-22 or PG 67-22 base asphalt.

In addition to the above requirements, the PG 70-22, PG 76-22, and 82-22 shall meet the following:

	PG 70-22	PG 76-22	PG82-22
Ring & Ball Softening Point, degrees F (degrees C), min.	53(128)	57(135)	65(150)
Elastic Recovery by means of Ductilometer, % min.	45	65	70

Test Procedures

Elastic Recovery by means of a Ductilometer

The Elastic Recovery shall be tested in accordance with AASHTO T301 at 77° F(25°C).

Screen Test

The procedure shall be to pour a 1,000 gram sample heated to 275° F(135° C) through a No. 10(2.0 mm) sieve. There shall be no lumps or particles retained on the sieve.

Viscometer Test

In addition to the above, a rotational viscometer, meeting ASTM D4402 requirements with a thermostatically controlled cell will be required at all hot mix asphalt mix plants using modified liquid asphalt products. A minimum of 1 test per day shall be run on samples taken from the contractor's storage tank. Viscosity values shall be in the following ranges when tested at 275° F.(135° C):

	PG-70-22	PG 76-22	PG 82-22
Viscosity range (cP)	650-3,000	1,000-3,000	2,000-4,000*

* PG82-22 must be stored at proper temperatures to maintain pumpability.

Materials Certification

A certification shall be furnished to the Engineer on each project stating that the asphalt cement furnished meets the Department's specification. Quality control and compliance testing shall be completed in accordance with asphalt suppliers approved quality control plan and in accordance with TDOT procedures.

Where blending or modification occurs after the material has left the storage tanks. A complete series of tests shall be conducted on a sample taken on the first day's production and biweekly thereafter for each grade being produced. Brookfield viscosity and DSR original tests shall be performed daily at the point of blending or modification. The DSR value $G^*/\sin\delta$ shall be ≥1.0 kPa at the high PG grade temperature (ie. 158° F(70° C) for PG 70-22).

In addition, the producer shall provide a temperature-viscosity curve with a recommended mixing temperature range. In order to develop a temperature-viscosity curve, it may be necessary to run the viscosity test at a higher temperature. This temperature would be dependent on the softening point of the modified asphalt cement.

If an SBR modifier is used, the SBR shall be pre-blended with the asphalt cement or added by means of an "in-line" motionless mixer. The "in-line" mixer shall be a Komax Model No. 30715A, Ross LPD Motionless mixer, Koch Static Mixer or other approved equal. The "in-line" motionless mixing unit shall provide a homogeneity value of 0.15 or less. The mixing unit shall be equipped with a port(s) for obtaining representative samples of the blended material in accordance with AASHTO T 40. The mixer shall be oil jacketed. The mixer shall have a minimum diameter of 1/2 in. (13 mm) larger than the asphalt supply line onto which it is installed. The manufacturer shall document to the Engineer that the above specifications will be obtained with the mixer furnished.

904.02-Blank

904.03-Emulsified Asphalts. Two types of emulsified asphalts shall be used under these specifications, both , anionic and cationic.

The manufacturer shall furnish samples of base asphalt used in the manufacture of asphalt emulsion, as directed by the Engineer.

All emulsified asphalts shall be homogenious, and shall adhere firmly to the surface of the mineral aggregate. Failure of the emulsified asphalt to perform satisfactorily on the job shall be deemed cause for rejection, notwithstanding its ability to pass laboratory tests.

A.Anionic Emulsified Asphalts.

In general, anionic emulsified asphalts shall conform to all the requirements of AASHTO M 140, for the type and grade specified.

In addition to the classes provided for in AASHTO M 140, a special mixing material (AE-3), a special priming material (AE-P) or a special tack(TST-1P) may be specified. These special materials shall conform to the following requirements:

Type	Special Mixing		Special Prime		Special Tack	
Grade	AE-3		AE-P		TST-1P	
Test Requirements:	Min.	Max.	Min.	Max.	Min.	Max.
Viscosity, Saybolt-Furol, 77° F(25° C), Sec.			10	50	10	75
Viscosity, Saybolt-Furol, 122° F(50° C), Sec.	50+	&Pumpable				
Settlement, 5 days, %		5	5	5		
24 hours					0.10	0.10
Sieve Test						
Stone Coating % coated)	90					
Distill. to 500° F (260°C)						
Residue, % by weight	70		45			
Oil portion of distillate, % by vol.		6		12		
Distillation to 400°F(205°C)						
Residue, % by weight			45		40	
Tests on residue from distillation						
(a)Float Test, 140° F (60° C), Sec.	200	20				
(b)Ductility, 77° F (25° C), cm	40					
(c)Ductility,111° F(4° C)					10	35
(d)Ash, by ignition, %		2				
Demulisibility (0.02 Normal/35ml)					+5	
Elastic Recovery@ 50°F(10°C)					25+	
Pen					75	150

The test requirement for settlement may be waived when the emulsified asphalt(special tack coat excepted) is used in less than 5 days' time; or the Engineer may require that the settlement test be run from the time the sample is received until it is used, if the elapsed time is less than 5 days.

The AE-3 shall be of such stability that it will remain constant and uniform while being mixed with dry or approximately dry aggregate, and

shall thoroughly and uniformly coat the entire surface of each fragment while being manipulated and incorporated into the work. The emulsified asphalt after being incorporated into the work shall show no signs of re-emulsifying.

B. Cationic Emulsified Asphalts.

Cationic emulsified asphalts shall conform to the requirements of AASHTO M 208, for the type and grade specified. Solubility in trichloroethylene will be required for information only every 3 months in the supplier's quality control program.

In addition to the classes provided in AASHTO M 208, a special priming material may be specified which is designated CAE-P. This material shall meet the requirements listed for AE-P except as follows:

(1) The Float Test shall be deleted.
(2) Penetration Test 77° F(25° C) shall be a minimum of 300.
(3) The particle charge shall be positive.

When approved by the Engineer, cationic emulsions may be substituted for anionic emulsions.

C. Emulsified Asphalts for Slurry Seal.

The emulsified asphalt for a Slow-Set Emulsified Asphalt Slurry Seal shall be Type CSS-1h-p meeting the requirements specified herein. The emulsified asphalt for a Quick-Set Emulsified Asphalt Slurry Seal and a Quick-Traffic Emulsified Asphalt Slurry Seal shall be Type CQS-1h-p meeting the requirements for Type CSS-1h-p with the following exceptions:

Residue, %	MIN. 60
Cement mixing test, %	(waived)

Unless otherwise specified on the Plans, a Quick-Set Emulsified Asphalt Slurry Seal shall be used.

The water shall meet the requirements of **Subsection 918.01**.

The latex modifier, when specified, shall be an unvulcanized styrene-butadiene rubber in liquid latex form. The cationic latex modifier shall conform to the following requirements:

Tests	Cationic Latex Modifier
Styrene/Butadiene Ratio, %	24/76 ± 1.5
Solids Content, %	60 Min.
ph	6.2 Max.
Lbs./gallon (kgs/liter):	
Wet Basis @ 77° F(25° C)	0.95(7.9) Min.
Dry Basis @ 77° F(25° C)	0.55(4.5) Min.

The manufacturer of the latex shall provide written certification of the results of the above noted tests.

Latex modified CSS-1h-p shall meet the requirements of AASHTO M-208 modified as follows:

Residue Requirements

Penetration @ 77° F(25° C)	30 Min.
Ductility @ 77° F(25° C)	150 +
@ 4° C	100 +
Softening Point, Ring and Ball, degrees C	54 +

The latex shall be combined with the asphalt emulsion at the emulsion mill to produce a homogeneous mixture.

The latex modified emulsion upon standing undisturbed for a period of 24 hours shall show no color striations, but shall be a uniform color throughout.

The latex modified asphalt emulsion shall meet the requirements of the Stretch Test which will be conducted as follows:

> Pour onto a quart(liter) friction can lid or similar container, enough of the emulsion to cover the surface to a depth of 1/16 to 1/8 in.(1.5 to 3 mm). Immediately, while the emulsion is still brown, embed with thumb pressure several stones or chips approximately ½ in.(13 mm) in size , 3/8 to 5/8 in.(10 to 16 mm) into the binder. Put the lid, or similar container containing the emulsion and aggregate into a 100° F(38° C) oven and allow to cure for a minimum of 8 hours. After the curing period, remove the lid and allow it to cool for one hour. Upon lifting a stone or chip from the binder, the asphaltic material must adhere to the aggregate and must elongate for a minimum distance of 3 in.(75 mm) without loss of adhesion and without breaking.

D. Emulsified Asphalts for Micro-Surface.

The emulsified asphalt for micro-surfacing shall be Type CSS-1h-p or CQS-1h-p meeting the requirements specified in subparagraph C for slurry seals above and the following requirements:

The latex or polymer modifier and other emulsifiers shall be milled into the asphalt cement and shall show no separation after mixing. The latex or polymer modified emulsified asphalt shall have a minimum softening point (Ring and Ball) of 135° F(57° C) when tested in accordance with AASHTO T 53. The blended asphalt mixture when combined with aggregate and mineral filler shall have the following characteristics:

1. Be capable of filling up to 1/2 in.(13 mm) wheel ruts in one pass.
2. Be capable of field regulation of the setting time.
3. Be suitable for nighttime placement.

The latex or polymer modified emulsified asphalt shall be accepted by certification from the manufacturer and must also meet the requirements of Subparagraph C for Slurry Seals above.

SECTION 918-MISCELLANEOUS MATERIALS

918.01-Water 823
918.02-Calcium Chloride 823
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Type B- Retarding admixtures
Type C- Accelerating admixtures
Type D- Water-reducing and retarding admixtures
Type E- Water-reducing and accelerating admixtures
Type F- Water-reducing, high range admixtures
Type G- Water-reducing, high range admixtures and retarding admixtures

Before any admixture is approved for use in portland cement concrete mixtures under these Specifications, the manufacturer of the admixture or the Contractor shall furnish the Department documentary evidence that the material proposed for use has been tested in accordance with the methods of test specified in AASHTO M 194 and meets the requirements of that Specificationand shall be listed on the Department's QPL. Documentary evidence shall be the results of tests conducted by a testing laboratory inspected at regular intervals by the National Bureau of Standards and approved by the Department. The Department may from time to time require a notarized certification from the manufacturer stating that the material is identical with that originally approved and has in no way been changed or altered.

(2) Air-Entraining Admixtures:

Air-Entraining Admixtures shall conform to the requirements of AASHTO M 154, except that the tests for bleeding, bond strength and volume change will not be required.

The Contractor will be required to furnish a material that appears on the Department's QPL.

A product may become approved by furnishing test data from a recognized laboratory showing that the air-entraining admixture proposed for use conforms to the requirements of these Specifications. A recognized laboratory is defined as one of the following: A State Transportation Department Laboratory; a Federal Highway Administration Laboratory; or other laboratories which are regularly inspected by the Cement and Concrete Reference Laboratory and approved by the Department.

(B) Bituminous Additives

(1) The anti-stripping additive shall be hydrated lime conforming to ASTM C 977 or other Heat Stable Asphalt Anti-stripping Additive containing no ingredient harmful to the bituminous material or the workmen, and shall not appreciably alter the specified characteristics of the bituminous material when added in the recommended proportions.

When hydrated lime is the anti-stripping additive, an amount equal to 1% by weight of the aggregate shall be used. A uniform lime coating of the aggregate shall be obtained in a manner

acceptable to the Engineer prior to adding the bituminous material to the mixture.

When an anti-stripping additive is used other than hydrated lime, the percentage of anti-stripping additive used is not to exceed 0.5%, but in no case shall the percentage of additive used be less than 0.3% by weight of the asphalt cement.

The Department will maintain a list of qualified antistripping productsNo product shall be used unless it appears on this list.

(2) Silicone additives. shall be mixed at the rate of 1 pt.(31 l) of silicone per 4 gal.(m^3) of diesel fuel. One half pt.(60 ml) of this mixture may be used per 1,000 gal.(3,800 l) of asphalt.

918.10-Masonry Stone. Masonry stone shall be sound, dense and durable, free from excessive cracks, pyrite intrusions and other structural defects. Stones which will be used with mortar shall be free from dirt, oil, or other material that might prevent good adhesion with the mortar.

When the crushed aggregate is subjected to 5 alternations of the sodium sulfate soundness test, the weighted percentage of loss shall be not more than 12.

918.11-Waterstops. Waterstops shall be of the type, shape and dimensions shown on the Plans.

A. Metallic.

Metallic waterstops shall be sheet copper conforming to the requirements of **Subsection 908.13**.

B. Nonmetallic.

Nonmetallic waterstops shall be manufactured from either natural rubber, synthetic rubber, or polyvinyl chloride (PVC) at the option of the Contractor. Waterstops shall be produced by such a process that, as supplied for use, they will be dense, homogeneous, and free from holes and other imperfections. The cross section of the waterstop shall be uniform along its length and transversely symmetrical so that the thickness at any given distance from either edge of the waterstop will be uniform.

Rubber waterstops shall be fabricated from a high grade thread-type compound. The basic polymer shall be natural rubber or a co-polymer of butadiene and styrene, or a blend of both. The compound shall contain not less than seventy percent by volume of the basic polymer, and the remainder shall consist of reinforcing carbon black, zinc oxide, accelerators, anti-oxidants, vulcanizing agents, and plasticizers, but shall contain no factice.

Samples taken from the finished waterstop shall meet the following requirements when tested in accordance with the current specified ASTM method of test.

ASTM

S T A T E **O F** **T E N N E S S E E**

(Rev. 06-01-06)
(Rev. 02-01-07)
(Rev. 12-30-08)
(Rev. 01-05-10)

March 1, 2006

Supplemental Specifications - Section 300

of the

Standard Specifications for Road and Bridge Construction

March 1, 2006

Subsection 303.08 (c) Second paragraph after (c), first sentence **Add** the word "exceeds" between the words "course" and "6 in. (150 mm)"

Subsection 303.13; Delete the second and third paragraphs and replace with the following:

> The weight of total moisture, as determined by dry weights, of the base material at the time of weighing in excess of 3 percentage points of optimum moisture content, will be deducted. When mixing is performed in a stationary plant, no direct payment for water will be made. When road mixing is performed, water added to the material during mixing at the direction of the Engineer will be made for payment.

SECTION 304-SOIL-CEMENT BASE Insert the following in the Table of Contents section of 304

"304.11-Thickness and Surface Tolerances."

Subsection 304.04 Last paragraph, add the word "be" in this section of the paragraph

"the entire section shall be reconstructed…"

Subsection 307.03b Composition of Mixtures, Revise entire subsection b to the following:

(b) Recycled Asphalt Pavement.

The Contractor may utilize asphaltic concrete removed from a Department project or other State Highway Agency project by an approved method and stored in a TDOT approved stockpile. Recycled Asphalt Pavement (RAP) combined with the appropriate aggregate, asphalt cement, and anti-strip additive when required shall produce a mixture that will otherwise meet all the requirements of **Subsection 903.06** and the requirements herein **Section 307**. RAP shall be allowed in each mix listed in the following table:

Mix Type	%RAP (Non-processed)	Maximum %RAP (Processed)	Maximum % RAP Processed and Fractionated	Maximum Particle size
307ACRL	0	00	-	-
307AS	0	00	-	-
307A	15	20	35	1 ½ in. (38 mm)
307B	15	30	35	1 ½in. (38 mm)
307BM	15	30	35	¾ in. (19 mm)
307BM2	15	30	35	¾ in. (19 mm)
307C	15	30	35	3/8 in. (9.5 mm)
307CW	15	30	35	½ in. (13 mm)
307CS	0	15	25	5/16 in. (8 mm)

RAP that has been crushed and screened or otherwise sized such that the maximum recycled material particle size is less than that listed in the table above prior to entering the dryer drum, shall qualify as "Processed". "Non processed" **RAP** shall be similar material that has not been crushed and screened or otherwise sized previous to its use. When RAP is processed over more than one screen, producing sources of various maximum particle size (i.e. – ¾" to ½", ½" to #4, etc.), it will be referred to as "fractionated", and larger percentages will be allowed as noted above. These increased percentages will only be allowed provided the individual fractions are introduced into the plant as separate material sources for increased control.

All mixes shall contain at least 65% virgin asphalt.

The Contractor shall obtain a representative sample from the recycled material stockpile and establish a gradation and asphalt cement content as required. The Contractor shall determine the gradation and asphalt content of the recycled material at the beginning of a project and every 2,000 tons(2,000 metric tons) thereafter. The stockpile asphalt cement content for all recycled material shall not vary by more than 0.8%. The stockpile gradation tolerance for all recycled material on each sieve is listed below.

3/8 in. (9.50 mm) sieve and larger± 10%
No. 4(4.75 mm) sieve.....± 8%
No. 8(2.36 mm) sieve.....± 6%
No. 30(600 µm) sieve .....± 5%
No. 200(75 µm) sieve .....± 4%

The mixture will be accepted for aggregate gradation and asphalt content based on extractions

A special design with asphalt content in the range of 5 to 7% shall be required where 307 C Mix is used as a surface on the shoulder.

The Contractor shall be responsible for his own sampling and testing of the planings as well as new materials for bid purposes, and for the submission of the job mix formula in accordance with Subsection 407.03. All additives shall be submitted to the Engineer for approval at the same time other materials are submitted for design verification.

If the Department has performed tests on the pavement to be cold planed, the results of all tests will be available at the Materials and Tests Division in Nashville, Tennessee during normal working hours. This information is advisory only and shall not be construed as necessarily complete nor accurate.

Where it is necessary to obtain a sample of the existing pavement for mix design, the Contractor shall mill the existing pavement to the full depth shown on the plans for pavement removal for a length of approximately 300 ft. (100 m) in an area approved by the Engineer. The removed pavement shall be replaced as specified on the plans or directed by the Engineer.

After mixing, the moisture content of the total mix shall be no more than 0.1% as determined by oven drying, and the provisions for lowering the temperature because of boiling or foaming shall not apply.

(c) Anti-Strip Additive - Asphaltic concrete mixtures (Grading A, AS, ACRL, B, BM, BM2, C, CS and CW) shall be checked for stripping by the following methods:

1. The Ten Minute Boil test for dosage rate and the Root-Tunnecliff procedure (ASTM D 4867) for moisture susceptibility.
2. For mixtures not requiring design - the Ten Minute Boil test for dosage rate and moisture susceptibility.

   * Root-Tunnecliff procedure (ASTM D 4867) shall not be used with the following mixtures: Grading A, AS, ACRL and B

If moisture susceptibility is indicated, then an approved anti-strip agent shall be mixed with the asphalt cement at the dosage recommended by the respective test and as specified in **Subsection 918.09(B).**

Subsection 307.08 Method of Measurement, Revise entire subsection to the following:

307.08-Method of Measurement. Aggregate and Asphalt Cement for Bituminous Plant Mix Base (Hot Mix) will be measured by the ton (metric ton) in accordance with the provisions of **Subsection 407.19**. Materials for prime or tack coat, if specified, will be measured as prescribed in **Section 402** or **403**, respectively.

If recycled mix is permitted, the completed mix, including new mineral aggregate, planings, asphalt cement and additive, shall be measured by the ton (metric ton) in accordance with **Section 109**. For bidding purposes, the asphalt cement content of the specified mixes shall be used in the chart below:

Mix Type	Asphalt Content
307 A	4.0%
307 B	4.3%
307 BM	5.0%
307 BM2	5.0%
307 C	5.0%
307 CW	6.0%
307 CS	6.5%

In the event that the Engineer sets an asphalt content other than that stated above, a price adjustment will be made based on the asphalt content set by the Engineer and the Monthly Bituminous Index for the specific grade asphalt on the mix design. The price adjustment will be calculated according to the following formula:

PA = [MBI x (DA-BA) x T] / 100

Where:

PA = Price Adjustment
MBI = Monthly Bituminous Index
DA = Percent asphalt set on the mix design
BA = Percent asphalt specified above to be used for bidding
T = Total tons(metric tons) asphalt mix for price adjustment

The liquid anti-strip additive will be measured by the gallon(liter) and paid as outlined in **Subsection 307.09**. Hydrated Lime will be measured by the ton (metric ton) and paid as outlined in **Subsection 307.09.**

No direct payment will be made for polymer or latex additives and cost thereof shall be included in the price bid for the modified asphalt cement or modified mixture.

Subsection 309.13; Delete the second and third paragraphs and replace with the following:

> The weight of total moisture, as determined by dry weights, of the base material at the time of weighing in excess of 3 percentage points of optimum moisture content, will be deducted. When mixing is performed in a stationary plant, no direct payment for water will be made. When road mixing is performed, water added to the material during mixing at the direction of the Engineer will be made for payment.

Subsection 312.08 Last sentence, Add the word “exceed”

> “1 layer shall not exceed 8 in. (200 mm).”

Subsection 313.02-Materials, Add the following to the end of this section

Liquid Membrane – Forming Compounds 913.05

Subsection 313.05; section (a) 1. Add to the end of the paragraph

> As an alternative to the steel wheel roller, the cement treated permeable base may be placed with a high-density screed with dual tamping bars.

Subsection 313.05; section (a) 2. Revise the first paragraph to read as follows

Curing; Immediately after spreading and compacting, the cement treated permeable base shall be cured by covering the entire surface and exposed edges with transparent or white polyethylene sheeting in accordance with **Subsection 501.18**, or a white pigmented wax base curing compound meeting the requirements of AASHTO M148. The polyethylene sheeting shall have a thickness of at least 4 mils (100 μm) and shall be held in place for a minimum of 7 days by a method approved by the Engineer. The surface of the cement treated permeable base shall be thoroughly wetted prior to placing the sheeting. The wax based curing compound shall be placed at a rate of 0.04 to 0.05 gallons per square yard (0.18 to 0.23 liter per square meter).

STATE OF TENNESSEE

March 1, 2006

(Rev. 02-09-09)
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(Rev. 05-09-2011)
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Supplemental Specifications - Section 400

of the

Standard Specifications for Road and Bridge Construction

March 1, 2006

Subsection 407.02 Materials, Add the following at the end of this subsection:

When warm mix asphalt additive is used as described in subsection **918.09(B)**, it shall be added by approved blending equipment at the contractor's mixing plant, or it shall be pre-mixed and delivered with the asphalt cement.

Subsection 407.03 (C) Replace the first paragraph with the following:

At least 14 working days prior to the scheduled start of production of any asphaltic paving mixture, the Contractor shall submit in electronic form(e-mail or on a floppy disk) a proposed Job Mix Formula and Laboratory Design, where applicable, prepared in accordance with the Marshall Method of Mix Design (AASHTO R-12), as modified by TDOT, or by Gyratory Compaction (AASHTO T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by means of the Superpave Gyratory Compactor). Regardless of which method is used, trial blends with at least 4 different asphalt contents (at least 2 above the optimum and 2 below the optimum) shall be made. When the gyratory method of compaction is utilized, the specimens shall be compacted to 65 gyrations with the optimum asphalt content and mixture volumetrics determined at that compaction level. If the specification requirements are not met, it will be necessary to make adjustments to the aggregate types and proportions. In addition the Contractor shall submit an asphalt barge certification with temperature-viscosity curve for each mixture to the Engineer for approval. A sample of each material to be used in the mix shall be delivered to the location designated by the Engineer.

Subsection 407.03 (D) 2 (c) Quality Control System: 8 d **Insert** as the second sentence

"The Contractor, at his risk, may continue to produce and place mixture after the first 500 tons without the test results complete, however all mixture subject to price adjustment or removal at the discretion of the Engineer if the test results do not comply with the specifications."

Subsection 407.03 (D), first paragraph, fourth sentence: **Remove** "on a random basis".

Subsection 407.03 (D) 2 (c) Quality control System, 6, last sentence: **Remove** "on a random basis".

Subsection 407.03 (D), **Table 407-01, Replace** "Required" with "Recommended" in the table heading.

Subsection 407.04a Bituminus Mixing Plant, Add the following to subsection "a" as the 12th bullet:

12. Warm Mix Asphalt process equipment.

    Modifications may be made to plants to reduce production and placement temperatures in accordance with subsection 407.21. Plant modifications for warm mix asphalt production temperatures shall be pre-approved by the department, and shall not detriment the plant's ability to maintain temperature control or mixture proportions.

    Modifications made to the plant to reduce mixing temperatures must meet the requirements listed for warm mix asphalt additives in the department's QPL.

Subsection 407.06-Bituminous Pavers: replace second sentence with:

"All paver extensions shall be full assembly extensions, including activated and heated screeds, auger extensions, auger guards, and throw-back blades to place mix beneath the auger gearbox."

Subsection 407.09 Replace subsection in its entirety with the following:

407.09 Weather Limitations. Bituminous plant mix may be placed on properly constructed and accepted sub-grade or previously applied layers provided the following conditions are met:

1. The sub-grade and the surface upon which the bituminous plant mix is placed shall be free of excessive moisture.
2. The bituminous plant mix shall be placed in accordance with the temperature limitations of the following table and only when weather conditions otherwise permit the pavement to be properly placed, compacted and finished.

TEMPERATURE LIMITATIONS

Compacted Thickness	Minimum Air or Surface Temperature	
	Unmodified mixes (PG 64, 67)	Modified mixes (PG 70, 76, 82)
1.5 in. (40 mm) or less	45° F (7° C)	55° F (13° C)
> 1.5 in. (40 mm) to < 3.0 in. (75 mm)	40° F (5° C)	50° F (10° C)
≥ 3.0 in. (75mm)	35° F (2° C)	45° F (7° C)

3. No bituminous plant mix, with a compacted thickness of 1.5 in. (40 mm) or less, shall be placed between November 30 and April 1; and further, no bituminous plant mix, with a compacted thickness greater than 1.5 in. (40 mm), shall be placed between December 15 and March 16.

4. The contractor may request for approval a variance from the above required temperature and seasonal limitations to pave at lower temperatures when there is a benefit to the public. The request shall be in writing, be submitted at least one week prior to the anticipated need, and must include a "Paving and Compaction Plan for Cold Weather" in accordance with the TDOT Procedure. The plan shall identify what practices and precautions the contractor intends to utilize to assure the mixture is placed and compacted to meet the specifications. The plan shall include compaction cooling curves estimating the time available for compaction, the intended production, haul, and compaction rates with paver and roller speeds estimated. Practices that should be considered include the addition of rollers, reduced production and paving rates, insulated truck beds, and heating the existing surface.

   If the Contractor cannot obtain the specified densities, then all paving operations shall cease and a new plan shall be developed. All mixture failing to meet specifications will be subject to price adjustments or removal and replacement at the Contractors expense.

Subsection 407.11 Preparation of Bituminous Material, Replace entire subsection with the following:

407.11-Preparation of Bituminous Material.

A. **Hot Mix Asphalt (HMA).** The bituminous materials for hot mixes shall be heated to the required mixing temperature in accordance with the following **Table B**:

Table B

PG Binder Grade	Minimum Temp.	Maximum Temp.
PG 64-22, PG 67-22	270° F(132° C)	310° F(154° C)
PG 70-22	290° F(143° C)	330° F(166° C)
PG 76-22	290° F(143° C)	330° F(166° C)
PG82-22	290° F(143° C)	330° F(166° C)

The temperature for Grading AS and Grading ACRL mixtures shall be between 225 and 275° F(110 and 135° C), except when modified binders are used, and then the temperatures shall be between 275 and 330°F (135 and 166°C). Aggregate should be coated and no visible drain down should occur in storage silos or hauling equipment."

B. **Warm Mix Asphalt (WMA).** The produced mixture may be subjected to reduced production and placement temperatures by means of either the addition of a chemical warm mix additive in accordance with subsection **918.09(B)** or by use of plant modifications in accordance with subsection **407.04(a).**

When either WMA technology is utilized, the maximum mixing temperature for any grade of asphalt cement shall be no more than 300ºF (135ºC). At the beginning of a day's production, the producer may produce up to five truckloads at temperatures in accordance with Table B in order to pre-heat placement equipment (pavers, transfer devices) prior to

producing WMA. The laboratory mixing and compaction temperatures shall be stated on the job mix formula during the mix design approval process. A tolerance of ±5.0ºF (2.8ºC) for each temperature will be allowed.

During test strip construction, the plant-produced WMA must exhibit the ability to meet test requirements for tensile strength ratio (TSR), conditioned tensile strength, Marshall Stability and flow, and boil test listed for HMA in specifications **307, 407,** and **411.**

Subsection 407.15 Following the eighth paragraph, Chart on **Density Requirements,** third column, Replace the word "number" with the word "No"

Subsection 407.15 To the Section "Any ADT", Shoulder Mix include **B, BM & BM2** mixes**.**

Any ADT

Shoulder Mix (B, BM, BM2, D, or E)	88	85
A S and A-CRL	None*	None
CS	None*	None

Subsection 407.15, Replace the 12th paragraph which begins "It is intended…" with the following paragraph:

Acceptance test must be selected randomly and be representative of the lot or sublot. Additional compaction after the acceptance test is acceptable but the original test result must be used to determine lot density. TDOT may take information only samples to spot check compaction. These tests shall not be used as acceptance test.

Subsection 407.20 B 1, Remove and replace the Quantity/Sublot Table with the following:

Quantity	Number of Sublots
3001-4500 tons	4 tests
2001- 3000 tons	3 tests
501-2000 tons	2 tests
Less than 500 tons	1 test

Subsection 407.20 B 3 (b), Add the following as the first sentence:

Washed gradation of the residual aggregate shall be performed according to AASHTO T-30.

Subsection 407.20, Table 407-2, Revise table to the following:

The percents passing the sieves will be determined in accordance with AASHTO T-30.

TABLE 407-2

ACCEPTANCE SCHEDULE OF PAYMENT (Asphalt Plant Mix Characteristics)			
Characteristics	**Pay Factor**	**Average Arithmetic Deviation of the Lot Acceptance Test from the Job Mix Formula**	
		1 Test	2 Tests or more
Asphalt Cement	1.00	0.00-0.30	0.00-0.25
Content ***	0.95	0.31-0.35	0.26-0.30
(Extraction or	0.90	0.36-0.40	0.31-0.35
ignition oven)	0.80*	over 0.40	over 0.35
Gradation			
3/8 In.	1.00	0.00-6.50	0.00-5.70
(9.5 mm),	0.95	6.51-7.08	5.71-6.20
Sieve and	0.90	7.09-7.66	6.21-6.69
Larger	0.80*	over 7.66	over 6.69
Gradation			
No. 4 Sieve**	1.00	0.00-4.62	0.00-4.00
(4.75 mm)	0.95	4.63-5.20	4.01-4.50
	0.90	5.21-5.77	4.51-5.00
	0.80*	over 5.77	over 5.00
Gradation			
No. 8 16, 30 & 50	1.00	0.00-3.80	0.00-3.30
(2.36 mm, 600 µm	0.95	3.81-4.46	3.31-3.91
& 300 µm ,) Svs**	0.90	4.47-5.12	3.92-4.52
	0.80*	over 5.12	over 4.52
Gradation			
No. 100 & 200	1.00	0.00-1.80	0.00-1.60
(150 µm & 75 µm)	0.90	2.01-2.20	1.76-1.90
Sieves**	0.95	1.81-2.00	1.61-1.75
	0.80*	over 2.20	over 1.90

*If approved by the Engineer, the Contractor may accept the indicated partial pay. The Department may require removal and replacement at no cost. The Contractor has the option to remove and replace at no cost to the Department at any time.

Subsection 411.03 Composition of Mixtures, Replace entire subsection with the following:

411.03-Composition of Mixtures.

(a) General Composition of mixtures used in this construction shall meet all applicable requirements of Subsection 407.03.

(b) The specified mineral aggregate and asphalt cement shall be combined in such proportions as to produce mixtures within the following master composition limits.

Proportions of Total Mixture, Per Cent by Weight

Surface Courses	Effective Combined Mineral Aggregate	Asphalt Cement
Grading D	93.0- 94.3	5.7-7.0*
Grading E	93.0- 94.3	5.7-7.0*
Grading E (shoulders)	92.0-94.7	6.0-6.5*

*If the effective combined specific gravity of the aggregate exceeds 2.80, the above proportions may be adjusted as directed by the Engineer. The upper limit for Flow values shall not apply to mixes with modified asphalt liquids.

Grading D

In addition to the other requirements of these specifications the composition of the mineral aggregate shall be such that when combined with the required amount of bitumen the resultant mixture shall have:

All Roads

Mix	Stabil. Min. lbft* (kN)	Flow 0.01 in. (mm) ***	Design Void content%*	Production Void Content %*	Min. VMA%*	Dust-Asphalt Ratio**
411D	2,000 (9.0)	8-16 (2-4)	4.0±0.2	3-5.5	14	0.6-1.2

*Tested in accordance with AASHTO T 245 with 75 blows of the hammer on each side of the test specimen, using a Marshall Mechanical Compactor.

**The dust to asphalt ratio is the percent of the total aggregate sample that passes the 200 mesh(75 µm) sieve as determined by AASHTO T 11 divided by the percent asphalt in the total mix

***Flow will only be required when using a non-modified binder (PG 64-22 or 67-22)

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

When limestone screenings or agricultural limestone are utilized, the maximum amount by weight of the mineral aggregate shall be 25% unless the material is shown to meet the same coarse surface aggregate requirements for limestone as listed in **Subsection 903.11 (c) Grade D** (Types I, II, III, IV). In no case shall the combined aggregate blend consist of less than 75% non-skid material. When natural sand is used as

fine aggregate, it shall be limited to a maximum amount of 25% by weight of the mineral aggregate. A maximum of 5% mineral filler meeting the requirements of **Subsection 903.16** may be substituted for an equal quantity of the limestone fines. If the mixture does not comply with the design criteria, another source of aggregate shall be required.

When gravel is used as the coarse aggregate for a 411 Grading D mix, a minimum of 20% by weight limestone screenings, agricultural limestone and/or mineral filler shall be required.

Grading E

In addition to the other requirements of these specifications where Grading E is used for the riding surface the composition of the mineral aggregate shall be such that when combined with the required amount of bitumen the resultant mixture shall have:

High Volume Roads (ADT over 1,000)

Mix	Stability Min. lbft* (kN)	Flow 0.01in. (mm) **	Design Void content %*	Production Void Content %*	Min. % VMA *
411 E	2,000 (9.0)	8-16 (2-4)	4.0±0.2	3-5.5	14

Low Volume Roads (ADT 1,000 and below)

Mix	Stability Min. lbft* (kN)	Flow 0.01in. (mm)**	Design Void content %*	Production Void Content %*
411 E	1,500 (6.75)	8-16 (2-4)	3.5±0.5	2-5

*Tested in accordance with AASHTO T 245 with 75 blows of the hammer on each side of the test specimen, using a Marshall Mechanical Compactor.

**Flow will only be required when using a non-modified binder (PG 64-22 or 67-22)

*** Minimum stability for shoulder mixes will be 1500 lb.ft. (kN) and optimum Asphalt Cement content for shoulder mixes shall be as directed by the Regional Materials Supervisor.

If the design criteria above cannot be obtained with the aggregate, submitted to the laboratory for design, another source of aggregate will be necessary.

(c) Recycled Asphalt Pavement

The Contractor may utilize asphalt pavement that has been removed from a Department project or other State Highway Agency project by an approved method and stored in a TDOT approved stockpile. Recycled Asphalt Pavement (RAP) combined with the appropriate aggregate, asphalt cement, and anti-strip additive when required shall produce a mixture that will otherwise meet all the requirements of **Subsection**

903.11 and the requirements herein **Section 411**. RAP shall be allowed in each mix listed in the following table:

Mix Type	%RAP (Non-processed)	Maximum %RAP (Processed)	Maximum % RAP Processed and Fractionated	Maximum Particle size
411D(PG64-22, PG67-22)	0	15	20	½ in. (12.5 mm)
411D(PG70-22)	0	10	15	½ in. (12.5 mm)
411D(PG76-22, PG82-22)	0	10	15	½ in. (12.5 mm)
411E(Roadway)	0	15	20	½ in. (12.5 mm)
411E(Shoulder)	15	30	35	½ in. (12.5 mm)

RAP that has been crushed and screened or otherwise sized such that the maximum recycled material particle size is less than that listed in the table above prior to entering the dryer drum, shall qualify as "Processed". "Non processed" RAP shall be similar material that has not been crushed and screened or otherwise sized previous to its use. When RAP is processed over more than one screen, producing sources of various maximum particle size (i.e. – ¾" to ½", ½" to #4, etc.), it will be referred to as "fractionated", and larger percentages will be allowed as noted above. These increased percentages will only be allowed provided the individual fractions are introduced into the plant as separate material sources for increased control.

All mixes shall contain at least 80% virgin asphalt except for 411E Shoulder Mix which shall have at least 65% virgin asphalt.

The Contractor shall obtain a representative sample from the recycled material stockpile and establish a gradation and asphalt cement content as required. The Contractor shall determine the gradation and asphalt content of the recycled material at the beginning of a project and every 2,000 tons (2,000 metric tons) thereafter. The stockpile asphalt cement content for all recycled material shall not vary from the Job Mix Formula by more than ± 0.8 %. The stockpile gradation tolerance for all recycled material on each sieve is listed below.

3/8in. (9.50 mm) sieve and larger .....± 10%
No. 4(4.75 mm) sieve.....± 8%
No. 8(2.36 mm) sieve.....± 6%
No. 30(600 µm) sieve.....± 5%
No. 200(75 µm) sieve.....± 4%

The Contractor will be responsible for his own sampling and testing of the RAP as well as new materials for bid purposes, and for the submission of the job mix formula in accordance with **Subsection 407.03**. After mixing, the moisture content of the total mix shall be no more than 0.1% as determined by oven drying, and the provisions for lowering the temperature because of boiling or foaming shall not apply.

The mixture will be accepted for aggregate gradation and asphalt content based on extractions or in accordance with AASHTO T 308

(d) Anti-Strip Additive

Asphaltic concrete surface mixtures (Grading D & E) shall be checked for stripping by the Ten Minute Boil test for dosage rate and ASTM D 4867(Root-Tunnecliff procedure) for moisture susceptibility.

If moisture susceptibility is indicated, then an approved anti-strip agent shall be mixed with the asphalt cement at the dosage recommended by the respective test and as specified in **Subsection 918.09(B).**

Subsection 411.09-Method of Measurement. Remove and replace the entire subsection with the following:

Subsection 411.09-Method of Measurement. Mineral Aggregate including Mineral Filler, when required, and Asphalt Cement for Asphaltic Concrete Surface (Hot Mix) will be measured as prescribed in Subsection 407.19. Mineral Filler when required will not be measured for payment separately, but will be included as mineral aggregate.

If recycled mix is permitted, the completed mix, including new mineral aggregate, planings, asphalt cement and additive, shall be measured by the ton (tonne) in accordance with Section 109. For bidding purposes, the asphalt cement content of the specified mix shall be used in the chart below:

Mix Type	Asphalt Content
411-D	5.9%
411-E Roadway	6.3%
411-E Shoulder	6.3%

In the event that the Engineer sets an asphalt content other than that stated above, a price adjustment will be made based on the asphalt content set by the Engineer and the Monthly Bituminous Index for the specific grade asphalt cement on the mix design. The price adjustment will be calculated according to the following formula:

PA = [MBI x (DA-BA) x T]/100

Where:

PA = Price Adjustment

MBI = Monthly Bituminous Index

DA = Percent asphalt set on the mix design

BA = Percent asphalt specified above to be used for bidding

T = Total tons (metric tons) asphalt mix for price adjustment

The liquid anti-strip additive will be measured by the gallon(liter) and paid as outlined in Subsection 411.10. Hydrated Lime will be measured by the ton(metric ton) and paid as outlined in Subsection 411.10.

No direct payment will be made for polymer or latex additives and cost thereof shall be included in the price bid for the modified asphalt cement or modified mixture.

Subsection 414.03, Revise entire section as follows:

414.03-Composition of Mixture. At least 2 weeks prior to beginning work the Contractor shall submit a signed original of a mix design covering the specific materials to be used on the project to the Materials and Tests Division for acceptance together with representative samples of each ingredient to be used in the mixture. The samples should contain information relative to sources, type of materials and project number.

This design must have been performed by a qualified laboratory. Once the materials are approved, no substitution will be permitted unless first tested and approved by the laboratory preparing the mix design. No work shall begin nor will any mixture be accepted until the Materials and Tests Division has evaluated and accepted the mix design.

The laboratory report will show the results of tests performed on individual materials, comparing their values to those required by this specification. Job aggregates will be used in all laboratory design tests. Mixing tests must pass at the maximum expected air temperature in ISSA T113.

Slurry Seal . The laboratory report will provide the following information on the slurry seal mixture.

Quick-Set Emulsified Asphalt Slurry Seal

Mixing Time Test, seconds @ 77° F(25° C) (TB #113),	120 minimum
Mix Time @ (50° and 100° F) (10° and 37.7° C)	(informational)
Set Time Tests	
30-Minutes-Blotter Test (TB #102)	no brown stain
Displacement Test	no displacement
Water Resistance Test @ 30 minutes (TB #102)	no discoloration
Wet Stripping Test, % coating (TB #114)	90% minimum
System Compatibility (TB #115)	Pass
Set Time Tests: 30 minutes (TB #139)	12 kg-cm minimum
Early Rolling Traffic Time: 2 hours (TB #139)	20 kg-cm minimum

Wet Track Abrasion Test, loss in g/ft2 (g/m2) (TB #100)	75(800) maximum 6 day soak

In addition to the tests specified above, the following test will be required on roadways having greater than 1500 ADT.

ISSA T #109	Test Method for Measurement of Excess Asphalt in Bituminous Mixtures by Use of a Loaded Wheel Tester and Sand Adhesion
1,500-3,000 ADT	Maximum 55grams/psf (590g/m^2) sand adhesion, 1,000 cycles @ 125 lbs. (57 kgs).
3,000+ ADT	Maximum 50grams/psf (540g/m^2) sand adhesion, 1,000 cycles @ 125 lbs.(57 kgs).

Slurry Seal Composition. Emulsified asphalt slurry seal shall be a uniform mixture of aggregate, emulsified asphalt, latex solids when specified on the Plans, mineral filler and water. Compatibility of all ingredients (including the mix set additive) of the mix shall be certified by the emulsified asphalt manufacturer.

The percent of residual asphalt based on the weight of the dry aggregate shall be between 7.5 and 13.5 with a mixture control tolerance of ±0. 50%.

The aggregate gradation and percent residual asphalt, as provided in the slurry seal design accepted by the Engineer, shall be maintained within the mixture control tolerances stated herein.

Portland cement may be added to obtain the desired dispersion and working characteristics of the slurry. Such addition shall be stated on the slurry seal design, shall not exceed 3% of the weight of the aggregate, and shall have a mixture control tolerance of ±0.25%.

Portland cement added for dispersion of the slurry seal shall be a commercial quality, non-air entraining cement and shall not be considered as mineral filler for the purpose of satisfying the gradation requirements of the aggregate.

The aggregate shall be prewetted with a minimum amount of water prior to blending with the emulsified asphalt to obtain a fluid, homogeneous slurry mixture of the proper consistency. No additional water above that quantity required by the slurry seal mix design shall be added to the slurry mix in order to obtain a more workable mixture.

Micro Surfacing. The laboratory report will provide the following information on the micro-surface mixture.

Mixing Time Test, secs @ 77° F (25° C), (T-102)	120 minimum
Mix Time @ 50 and 100° F (10° C and 37.7° C)	(informational)
Set Time Tests: 30 minutes (T-139)	12 kg-cm minimum

Early Rolling Traffic Time: 60 minutes (T-139)	20 kg-cm minimum
Wet Stripping Test, % coating (T-114)	90% minimum
Wet Track Abrasion Test, loss in g/ft^2 (g/m^2) (T-100)	75 (800) max 6 days 50 (538) max. 1 hour
Measurement of Excess Asphalt (T-109)	Max. 50 $grams/ft^2$ (540 $grams/m^2$) Sand Adhesion, 1,000 Cycles @ 125 lbs. (57 kgs).
Classification Compatibility (T-144)	11 pt. minimum

Micro-Surface Composition. For the paving mixture, the design shall verify the functioning of the set regulating additives and shall present certified test results for the Engineer's approval. Aggregate in the mixture shall represent material to be used on the project.

The Engineer shall approve the design prior to use. Proportions for the design shall be within the following limits:

Modified Emulsified Asphalt Residue by Dry Wt. of Aggregates	5.0-9.0%
Mineral Additive by Dry Weight of Aggregate	0.5%-3.0%
Latex or Polymer Based Modifier provide the specified properties	3% minimum and as required to
Mix Set Additive	As required to provide the specified properties
Water	As required to produce consistency

Portland cement may be added to obtain the desired dispersion and working characteristics of the mix. Such addition shall be stated on the micro-surface design, shall not exceed 3% of the weight of the aggregate, and shall have a mixture control tolerance of ±0.25%.

Portland cement added for dispersion shall be a commercial quality, non-air entraining cement and shall not be considered as mineral filler for the purpose of satisfying the gradation requirements of the aggregate.

The mixture shall also be proportioned such that the test strip requirements in **Subsection 414.06** are achieved.

Applicable Specifications. The following specifications and test methods form a part of this specification.

Title	Source
Mixing, Setting and Water Resistance Test to Identify "Quick-Set" Emulsified Asphalts	ISSA TB-102
Wet Track Abrasion of Micro Seals	ISSA TB-100
Measurement of Micro-Seal Consistency	ISSA TB-106
Test Method for Measurement of Excess Asphalt in Bituminous Mixtures by Use of a Loaded Wheel Tester	ISSA TB-109
Outline Guide Design Procedure for Slurry -Seal	ISSA TB-111
Method to Estimate Micro-Seal Spread Rates and to Measure Pavement Macrotexture	ISSA TB-112
Trial Mix Procedure for Slurry -Seal Design	ISSA TB-113
Wet Stripping Test for Cured Slurry-Seal Mixes	ISSA TB-114
Test Method to Classify Emulsified Asphalt/Aggregate Mixture Systems by Modified Cohesion Tester. Measurement	ISSA TB-139

of Set and Cure Characteristics	
Classification Compatibility	ISSA TB-144
Design, Testing and Construction of Micro-Seal	ASTM D 3910
Quantitative Extraction of Bitumen for Bituminous Paving Mixtures	ASTM D 2172

The blended asphalt mixture, when combined with aggregate and mineral filler, shall have the following characteristics:

1. Be capable of filling up to ½ in. (13 mm) wheel ruts in one pass.
2. Be capable of field regulation of the setting time.
3. Be suitable for nighttime placement.

Subsection 414.04, Revise subsection as follows:

414.04-Equipment. All equipment necessary for the satisfactory performance of this work shall be on hand and approved before the work is permitted to begin. All equipment, tools, and machines used in the performance of this work shall be maintained in satisfactory working condition. The Contractor shall have available at all times a device capable of determining aggregate moisture within 3 minutes.

All trucks shall be covered immediately after loading with a cover of canvas or other suitable material. The cover shall lap down along the sides and rear of the truck bed a minimum of 6 in. (150 mm) and be secured by tie downs at a maximum of 5 ft. (1.5 m) spacing along the sides and rear of the truck bed. All trucks must be equipped to meet the above requirements prior to commencing hauling operations.

Power brooms, power blowers, air compressors, water flushing equipment and hand brooms shall be capable of thoroughly cleaning all cracks and the old surface. Hand squeegees, hand brooms, shovels and other incidental equipment shall be provided as necessary to perform work.

Mixing Equipment. The mixing equipment shall be re-supplied with all materials while depositing the mixture on the roadway in order provide a continuous, non-stop surfacing operation. The paving mixture shall be produced in a self-propelled, front feed, continuous loading, mixing machine equipped with a positive, non-slipping aggregate delivery system and an interconnected, positive displacement water-jacketed gear pump to accurately proportion ingredients.

The mixing machine shall be equipped with an approved fines feeder that has an accurate metering device or method to introduce a predetermined amount of mineral filler into the mixer at the same time and location as the mineral aggregate. A spray bar shall be provided to completely wet the aggregate dropping down to the pug mill with additive and water. The twin-shafted multi-blade pug mill shall be a continuous flow type and a minimum of 50 in. (1.25 m) long. The emulsion shall be introduced above the third point of the mixer to ensure proper premixing of the aggregate, cement, additive and water when the modified emulsified asphalt is added. Blade size and side clearances shall meet the equipment manufacturer's recommendations.

Mixing shall be done in a manner that does not cause premature breaking of the emulsified asphalt. The mixing unit of the mixing chamber shall be capable of thoroughly blending all ingredients.

The mixer shall be equipped with a remote forward speed control at the back mixing platform so the back operator can control forward speed and level of mixture in paving or rut box. Effective April 1, 2006, the Contractor shall provide a computerized material monitoring system with integrated material control devices that are readily accessible and positioned so the amount of each material used can be determined at any time. The mixer shall be equipped with a back-up electronic materials counter that is capable of recording running count totals for each material being monitored. The mixer shall be equipped with a radar ground measuring device. Each material control device shall be calibrated prior to each mix application and as often thereafter as deemed necessary by the Engineer. The computer system shall have the capability to record, display and print the following information:

- Individual sensor counts for emulsion, aggregate, cement, water and additive
- Aggregate, emulsion, and cement output in lbs.(kgs) per minute
- Ground travel distance. The mixer shall be equipped with a Radar Ground metering device
- Spread rate in lbs./s.y.(kgs/m^2)
- Percentages of emulsion, cement, water and additive
- Cumulative totals of aggregate, emulsion, cement, water and additive
- Scale factor for all materials

The computer system shall be functional at the beginning of work, and must be functional during each calibration.

The mixing machine shall be equipped with a water pressure system and fog type spray bar, adequate for complete fogging of the surface preceding spreading equipment of the mixture.

The mixing machine shall include controls for proportioning and calibrating the aggregate feed. The aggregate feed device shall be equipped with a revolution counter so that the amount of aggregate used may be determined at any time and shall have a positive locking feed gate.

The emulsion pump shall be of the positive displacement type and shall be equipped with a device so that the amount of emulsion used may be determined at any time. The emulsion pump, meter and piping shall be arranged to afford a means to calibrate the meter by weighing a metered volume. The pump shall deliver the emulsion to the mixer box at a uniform rate which shall not vary more than 2% from the required quantity.

The water pump shall be equipped with a minimum of 2 valves. One valve shall establish the required water flow. The other valve shall be a quick acting valve to start and stop the water flow.

The mixing machine shall have sight gauges located at the material storage tanks for the asphalt emulsion and water.

The mixing machine shall be equipped with approved metering devices so that it can be accurately calibrated and the quantities of materials used during any 1 period can be closely estimated. In the event that the metering devices stop working properly, the mixing machine shall no longer be used until necessary repairs have been made.

Satisfactory means shall be provided to afford positive interlocking control between the flow of aggregate from the bins and the flow of emulsion from the pump. Each mixing unit shall be

calibrated in the presence of the Engineer prior to construction. The documentation shall include an individual calibration of each material at various settings, which can be related to the machine's metering devices. When calibrating the emulsion system, a minimum of 3 tests shall be run, with each test run being a minimum of 40 gal. (150 liters). Calibration of the aggregate delivery system shall require tests at 3 different gate settings with 2 test runs at each gate setting and a minimum of 425 lbs. (193 kgs) per test run. Calibration of the filler(cement) delivery system shall require 3 tests at a minimum of 25 lbs. (11 kgs) per test. The scales used shall be certified. No machine will be allowed to work on the project until the calibration has been completed and accepted. Additional calibrations may be required during the process of the work as directed by the Engineer.

Spreading Equipment. Attached to the machine shall be hydraulically adjustable(adjustable while applying mixture) type spreader box with a positive screed adjustment for yield control and a positive adjustment for the joint matcher. The box shall be attached to the mixer, equipped with ribbon flights mounted on an adjustable shaft to continually agitate and distribute the materials throughout the box. The box shall be equipped with curb bumpers and replaceable runners with a minimum of 5 ft. (1.5 m) long end runners. The box shall be equipped with a sufficient walkway to provide access to either side of the spreader box without walking through the freshly laid material. The spreader box shall be heavy duty with crossbracing for rigidity and a manufacturer's weight not less than 1,400 lbs. (635 kgs) at a width of 12 ft. (3.6 m). The box must be capable of laying mix to a width of 14 ft. (4.3 m). The equipment shall provide sufficient turbulence to prevent the mix from setting in the box or causing excessive side build-up or lumps. To prevent the loss of the mixture from the box, the Contractor shall attach flexible seals, front and rear, in contact with the road. The full width application box shall be equipped with a secondary strike-off located approximately 2 to 3 ft. (0.5 to 1.0 m) behind the primary strike-off to minimize transverse corrugations. The secondary strike-off shall have elevation and width adjustments similar to the primary strike-off. It shall have a pivot point where it can be tilted for texturing or raised completely off the surface. Rut filling shall require a steel or high density strike-off on the spreading equipment (as approved by the engineer) or the use of a rut box. A rut box shall be used for filling ruts in excess of 3/8 in. (10 mm) unless otherwise specified on the plans. The Contractor shall operate the spreading equipment in such a manner to prevent the loss of the mixture on super-elevated curves. Mixture shall be spread to fill cracks and minor surface irregularities and achieve a uniform skid-resistant surface without causing skips, lumps or tears in the finished mat.

For slurry seals, the use of burlap drags or other drags necessary to obtain the desired finish, shall require approval by the Engineer. Drags having excessive build-up shall be replaced. Drags shall be kept in a completely flexible condition at all times. No drags shall be used on Micro-surfacing.

Subsection 414.06, Revise subsection as follows:

414.06-Application. Prior to the placement of the mixture, a tack coat of CQS-1h or CQS-1hp emulsion shall be applied with an asphalt distributor. The tack coat shall consist of 1 part emulsion and 2 parts water. The application rate shall be 0.05 to 0.10 gal./s.y.(0.2 to 0.5 liters/m^2) of the diluted emulsion. The actual application rate shall be determined by the Engineer. The method of application of the tack coat shall be in accordance with **Section 403**.

The emulsified asphalt slurry seal shall be applied at a rate of 16 ±2 lbs./s.y.(of 8.75 ±1 kgs/m^2) based on dry aggregate weight unless otherwise specified on the Plans. The rate of application shall be varied within the range specified above as required by the condition of the pavement to obtain a minimum thickness of 1/8 in. (3 mm) above the high points of the milled areas and ¼ in. (6 mm) thickness on unmilled areas.

Micro-surface shall be applied as follows:

- Rutfill Course. If a rut fill course is specified, apply enough material to fill the wheel paths without excess crowning (overfilling). An excess crown is defined as 1/8 in. (3 mm) after 24 hours of traffic compaction. Apply rut fill courses in widths from 5 to 6 ft. (1.5 to 1.8 m) for each wheel path. Provide a smooth, neat seam where 2 rut fill passes meet. Take care to restore the designed profile of the pavement cross-section. Feather the edges of the rut fill course to minimize the use of excess material.
- Leveling Course. If a leveling course is specified, apply at a rate of 14 ±2 lbs /s.y. (7.6 ±1.1 kgs/m^2) based on dry aggregate.
- Surface Course. If a surface course is specified and it is placed over a leveling course, apply at a rate of 18 ±1 lbs/s.y. (8.7 ±0.6 kgs/m^2) based on dry aggregate. If a surface course is specified and it is not placed upon another micro-surfacing course, apply the paving mixture at a minimum rate of 22 lbs/s.y. (11.9 kgs/m^2) based on dry aggregate.

Micro-surface shall be applied at the rates as specified on the plans for leveling and surface courses.

The mixture shall be applied based on dry aggregate weight as specified on the plans.

The maximum allowable speed of the machine shall be 130 ft. (40 m) per minute. When rut filling, the maximum allowable speed shall be determined by the Engineer. The final surface seal shall be placed uniformly across the width of the traffic lane unless otherwise specified or directed. The action of the squeegee shall permit the mix to flow freely leaving a smooth, uniformly textured surface.

Unless otherwise directed by the Engineer, the surface shall be pre-wetted with water by fogging ahead of the spreader box. Pre-wetting shall be closely controlled to prevent accumulation of water to the point of running off or puddling.

As the aggregate and emulsion are being loaded into the aggregate/emulsion support trucks or mixing machine, the aggregate shall be given a final screening by sieving it through screening equipment capable of removing any random oversize material.

The mixture shall be of the desired consistency when deposited on the surface after which no additional elements shall be added. A sufficient amount of mixture will be carried in all parts of the spreader at all times so the complete coverage is obtained. No lumping, balling or unmixed aggregate shall be permitted. No segregation of the emulsion and aggregate fines from the coarse aggregate will be permitted. If the coarse aggregate settles to the bottom of the mix, the mix will be removed from the pavement. The mixture shall have proper consistency so that excessive splattering and excessive free water is avoided. The spraying of water into the spreader box during lay down operations will not be permitted. Hand tools, lutes and squeegees shall be used to spread mix on areas not accessible to the machine spreading equipment. Rolling with a pneumatic-tired roller shall be required after proper curing for sections of pavement not to

be exposed to traffic. The roller shall be equipped with tires with a pressure of 40-60 psi(275 to 425 kPa).

Quality Control: The Contractor shall produce a mixture that will be in compliance with the mix design and the quality control tolerances. The Slurry Seal or Micro-Surface shall be applied at the rates as specified on the plans. The methods described in this section shall be used by the Contractor to measure compliance. Contractor shall maintain all quality control documentation and make available to the Engineer or Project Inspector upon request or at completion of work.

a. Asphalt Content – The Contractor shall calculate the % asphalt content of the mixture from the equipment computer display readings randomly, a minimum of 3 times a day. The quality control tolerances from the mix design is ± 0.5%.

b. Application Rate – The Contractor shall calculate the yield of the course being placed from the equipment computer display readings randomly, a minimum of 3 times a day. The quality control tolerance from the specified application rate is ±2 lbs/s.y. (±1 kg/m^2).

c. Documentation – The Contractor shall maintain a daily report and a lot sheet as follows:

   1. Daily Report – The daily report shall include the following information:
      - Aggregate used, ton(metric ton) (dry)
      - Slurry or Micro-Surfacing emulsion used, ton(metric ton)
      - Bituminous Materials for Tack Coat and for Fog Seal, ton (metric ton)
      - Cement used, ton(metric ton)
      - Water used in mixture, gallons(liters)
      - Additive used in mixture, gallons(liters)

d. Test Strip Construction - Prior to production application, the Contractor shall place a 1,000 ±50 ft. (300 ±15 m) test section to verify a quick traffic system is being used. The test strip shall be placed at the same time as paving is to take place, night or day, and under the same ambient conditions. The test strip shall be able to carry normal traffic within 60 minutes. If normal traffic cannot be carried, the emulsion or mixture must be adjusted and another test strip will be required.

   Lot Sheet - The project shall be segmented into lots with any 1 lot not to exceed 20,000 s.y.(16,700 m^2). For each lot the Contractor shall maintain a lot sheet, providing the following information:

- Control Section, Job Number, Route, Engineer (Project Inspector)
- Date, Air Temperature
- Control Settings, Calibration Values, Unit Weight of Emulsion (lbs per gallon) (kgs per liter), Percent residue in Emulsion.
- Beginning and Ending Intervals
- Computer display readings for material usage (Beginning, and Ending, and Total)
- Length, Width, Total Area (s.y.) (m^2), (lbs.) (kg) of Aggregate, lbs. (kg) of Emulsion, lbs. (kg) of Cement.
- Percent of each Material, Percent of Asphalt Cement, Application Rate, Combined Application Rate (lbs./yd^2) (kgs/m^2)

- Mix Design (Percent Portland Cement, Percent Emulsion, Percent Asphalt Cement)
- Contractors Authorized Signature
- Calibration Forms

Subsection 414.09, Revise subsection as follows:

414.09-Weather Limitations. Micro-surface and slurry seal shall be placed only when the pavement surface temperature and the ambient air temperature are a minimum 50° F(10° C) and rising. These applications will not be placed during foggy or rainy conditions. Placement shall be limited to the period from April 1 to October 31.

Subsection 414.11, Revise the second paragraph to as follows:

For bidding purposes, the emulsified asphalt content on the slurry mix design shall be 15% and for micro-surfacing design the asphalt content shall be 12%. In the event that the Engineer sets an emulsified asphalt content for slurry seal other than that stated above, a price adjustment will be made based on the emulsified asphalt content set by the Engineer and the invoice price of the emulsified asphalt F.O.B. the project delivery point. The price adjustment will be calculated according to the following formula:

Subsection 415.02, (**Delete** the third paragraph) "When milling the Interstate…"

S T A T E O F T E N N E S S E E

(Rev. 09-01-09)
(Rev. 02-06-10)
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March 1, 2006

Supplemental Specifications - Section 900

of the

Standard Specifications for Road and Bridge Construction

March 1, 2006

Subsection 903.03 Coarse Aggregate for Concrete, Revise the fourth paragraph to the following:

Coarse aggregate for prestressed concrete shall be Size No. 57 or Size No. 67, **Subsection 903.22,** as may be specified or directed. Coarse aggregates for precast concrete shall include any size fractions of **Subsection 903.22**, as may be specified or directed.

Subsection 903.12 (b) Aggregate for Micro-surface. Revise table as shown below:

GRADATION LIMITS FOR AGGREGATE

BASED ON WASH GRADATION

Sieve	Design Master Range (Total Percent Passing)	Mixture Control Tolerances
3/8 in.(9.5 mm)	100	
No. 4(4.75 mm)	70-98	±6.0
No. 8(2.36 mm)	45-70	±5.0
No. 16(1.18 mm)	28-50	±5.0
No. 30(600 µm)	19-34	±4.0
No. 50(300 µm)	12-25	±4.0
No. 100(150 µm)	7-18	±2.0
No. 200(75 µm)	4-15	±2.0

Subsection 904.03 Emulsified Asphalts. Replace Entire subsection with the following:

904.03-Emulsified Asphalts. Emulsified asphalts used on TDOT projects shall only be from Certified Emulsified Asphalt Suppliers that have an approved Quality Control Plan in accordance with TDOT Standard Operating Procedures.

Two types of emulsified asphalts shall be used under these specifications, both, anionic and cationic.The manufacturer shall furnish samples of base asphalt used in the manufacture of asphalt emulsion, as directed by the Engineer.

All emulsified asphalts shall be homogeneous, and shall adhere firmly to the surface of the mineral aggregate. Failure of the emulsified asphalt to perform satisfactorily on the job shall be deemed cause for rejection, notwithstanding its ability to pass laboratory tests.

A. Anionic Emulsified Asphalts.

In general, anionic emulsified asphalts shall conform to all the requirements of AASHTO M 140, for the type and grade specified.

In addition to the classes provided for in AASHTO M 140, a special mixing material (AE-3), a special priming material (AE-P) or a special tack(TST-1P) may be specified. These special materials shall conform to the following requirements:

TYPE	**Special Mixing**		**Special Prime**		**Special Tack**	
GRADE	**AE-3**		**AE-P**		**TST-1P**	
TEST REQUIREMENTS:	***Min.***	***Max.***	***Min.***	***Max.***	***Min.***	***Max.***
Viscosity, Saybolt-Furol, 77° F(25° C), Sec.	-	-	10	50	10	75
Viscosity, Saybolt-Furol, 122° F(50° C), Sec.	50+ &Pumpable		-	-	-	-
Settlement, 5 days, %	-	5	-	5	-	5
Sieve Test, %	-	-	-	0.10	-	0.10
Stone Coating, %	90	-	-	-	-	-
Residue by distillation*, %	70	-	45	-	55	60
Oil portion of distillate, % by vol.	-	6	-	12	-	-
Tests on residue from distillation:						
Float Test, 140° F (60ºC),	20	-	20	-	-	-
Ductility, 77° F (25ºC), cm	40	-	40	-	-	-
Ductility, 40° F (4ºC), cm	-	-	-	-	10	35
Ash, by ignition, %	-	2	-	-	-	-
Demulsibility, 35 ml, 0.02 *N* $CaCl_2$, %	-	-	-	-	5	-
Elastic Recovery @ 50°F (10°C)	-	-	-	-	25	-
Penetration	-	-	-	-	75	150

*TST-1p shall be distilled at 400ºF (205ºC). AE-3 and AE-P shall be distilled at 500ºF (260ºC).

The test requirement for settlement may be waived when the emulsified asphalt (special tack coat excepted) is used in less than 5 days' time; or the Engineer may require that the settlement test be run from the time the sample is received until it is used, if the elapsed time is less than 5 days.

The AE-3 shall be of such stability that it will remain constant and uniform while being mixed with dry or approximately dry aggregate, and shall thoroughly and uniformly coat the entire surface of each fragment while being manipulated and incorporated into the work. The emulsified asphalt after being incorporated into the work shall show no signs of re-emulsifying.

B. Cationic Emulsified Asphalts.

Cationic emulsified asphalts shall conform to the requirements of AASHTO M 208, for the type and grade specified. Solubility in trichloroethylene will be required for information only every 3 months in the supplier's quality control program.

In addition to the classes provided in AASHTO M 208, a special priming material may be specified which is designated CAE-P. This material shall meet the requirements listed for AE-P except as follows:

When approved by the Engineer, cationic emulsions may be substituted for anionic emulsions.

CRS-2P emulsion shall meet the testing requirements listed for CRS-2P in Table 1 of AASHTO M 316. The requirement for ductility at 4ºC shall be waived, and the emulsion residue shall have a minimum softening point (Ring and Ball) of 125ºF (52ºC).

C. Emulsified Asphalts for Slurry Seal.

The emulsified asphalt for Emulsified Asphalt Slurry Seal shall be Type CQS-1h conforming to the requirements in AASHTO M 208 with the following exceptions:

Residue, %	MIN. 62
Cement mixing test, %	(waived)

The water shall meet the requirements of **Subsection 918.01**.

D. Emulsified Asphalts for Micro-Surface.

The emulsified asphalt for micro-surfacing shall be Type CQS-1h-p conforming to the requirements listed for CQS-1h in AASHTO M 208 with the following exceptions:

Residue, %	MIN. 62
Cement Mixing Test, %	(waived)
Ductility @ 77°F (25°C)	MIN. 70

Residue shall be obtained by distillation at 350°F (177°C)

The latex or polymer modifier and other emulsifiers shall be styrene butadiene rubber (SBR) or natural latex, and shall be milled into the asphalt cement and shall show no separation after mixing. The latex or polymer modified emulsified asphalt shall have a minimum softening point (Ring and Ball) of 135° F(57° C) when tested in accordance with AASHTO T 53. The blended asphalt mixture when combined with aggregate and mineral filler shall have the following characteristics:

1. Be capable of filling up to 1/2 in.(13 mm) wheel ruts in one pass.
2. Be capable of field regulation of the setting time.
3. Be suitable for nighttime placement.

The latex shall be combined with the asphalt emulsion at the emulsion mill to produce a homogeneous mixture.

The latex modified emulsion upon standing undisturbed for a period of 24 hours shall show no color striations, but shall be a uniform color throughout.

The latex or polymer modified emulsified asphalt shall be accepted by certification from the manufacturer.

Subsection 908.03-Permanent Steel Bridge Deck Forms; Delete ASTM A446 and A525, and **Replace** with A653

Subsection 908.03(C) First paragraph. Change to read as follows:

All high strength bolts, nuts and washers shall be certified to have met the specified tests identified in their individual ASTM Specification designations, both as individual components, and as assemblies (Bolts, Nuts, and Washers).

Subsection 908.07-Gray Iron Castings. Reviseentire subsection to the following:

908.07-Gray Iron Castings. All castings shall be of the type specified and shall be within reasonably close conformity with the dimensions shown on the Plans. The castings shall conform to AASHTO M105, with the additional requirements herein, and unless otherwise specified all castings shall be Class 30.

Test bars for tension testing shall be cast in accordance with AASHTO M 105, Table 2, Test Bar B.

All castings shall be cleaned of sand and scale by sand blasting or other effective methods so as to present a smooth, clean, and uniform surface.

Gray iron castings shall have the date of manufacture cast into each unit.

Manhole castings shall have the lid and lid seat of the rim machined to form a true bearing.

All castings shall weigh at least 95% of the theoretical weight shown on the Plans.

Subsection 914.09 Polyvinyl Chloride Pipe (PVC). Revise entire subsection to the following:

914.09-Polyvinyl Chloride Pipe(PVC) . Pressurized pipe accepted under this Specification shall conform to the requirements of ASTM D 1785. Pipe Culverts accepted under this Specification shall conform to the requirements of ASTM D 1784.

Subsection 914.10-High Density Polyethylene Plastic Pipe. Revsie entire subsection to the following:

914.10, High Density Polyethylene Plastic Pipe. Pipe Culverts accepted under this specification shall conform to the requirements of AASHTO M 294, Type S. Slope Drains accepted under this specification shall conform to the requirements of AASHTO M 294, Type C or Type S.

Subsection 916.02 (a) Aluminum flat Sheet; **Revise** as shown below:

(a). Aluminum flat sheet (sign blanks) and plates (permanent and temporary) shall meet ASTM B 209, Alloy 6061 T6 or 5052-H38. Recycled aluminum flat sheet (sign blanks) meeting ASTM B209, Alloy 6061 T6, or 5052-H38 may be used for temporary signing only. Composite material sign blanks (temporary signing only) shall be selected from the Department's QPL. The sign blanks shall be flat and shall contain no visible lateral bow.

Subsection 918.08: Replace entire section, with the following:

The marking material shall be prefabricated plastic consisting of white or yellow pigmented plastic with reflective glass spheres uniformly distributed throughout the entire cross sectional area and shall be capable of being affixed to bituminous or Portland cement concrete pavement by either a pressure sensitive pre-coated adhesive or liquid contact cement. The material shall be provided complete in a

form that will facilitate rapid application and protection during shipment and storage. Solvents, adhesives and necessary equipment for proper application for life shall be in accordance with manufacturer's instructions. The material shall be manufactured and packaged in such a manner to permit storage at normal shelf temperatures for periods of up to one year after purchase. Contact cements, where used, shall have a shelf life of 6 months. The material shall mold itself to pavement contours, breaks, faults, and the like by action of traffic at normal pavement temperatures. The material shall have resealing characteristics so that it will fuse with itself and with previously applied marking materials of the same composition under normal conditions of use.

Prefabricated legends and symbols must conform to the applicable shapes and sizes as outlined in the Manual on Uniform Traffic Control Devices for Streets and Highways. These pavement markings shall be on the Department's QPL.

Materials: The marking material shall be a 60 mil (1.50 mm) retroreflective pliant polymer conforming to the following requirements. The retroreflective pliant polymer pavement marking film shall consist of a mixture of high quality polymeric materials and pigments with 1.50 minimum refractive index glass spheres uniformly distributed throughout its cross sectional area, and with a reflective layer of beads bonded to the top surface. Composition shall be as follows:

Material	Min. % by Weight
Resins & Plasticizers	20
Pigments	30
Graded Glass Beads	33

This material shall be capable of adhering to asphaltic or Portland cement concrete, by means of a pressure sensitive, pre-coated adhesive, or by a liquid contact cement applied at the time of installation.

Tensile Strength. The film shall have a minimum tensile strength of 40 psi (275 kPa) of cross section when tested according to ASTM D 638. A sample 6 x 1 x 0.06 in.(150 x 25 x 1.5 mm) shall be tested at a temperature between 70° and 80° F(21 to 27° C) using a jaw speed of ¼ in.(6 mm) per minute.

Elongation. The film shall have a minimum elongation of 75% when tested according to ASTM D 638.

Plastic Pull Test. A test specimen made the same size as described under "Tensile Strength" above shall support a dead weight of 4 lbs. (1.8 kgs.) for not less than 5 minutes at a temperature between 70 and 80° F (21 to 27° C).

Pigmentation. The pigments shall be selected and blended to provide a marking film that is white or yellow conforming to standard highway colors through the expected life of the film.

Pigments. Sufficient titanium dioxide pigment meeting Federal Specification TT-P-442 shall be used in white markings to insure a dense opaque marking. Pigments shall include titanium dioxide for white plastic and C. P. medium chrome yellow for yellow plastic.

Sufficient medium chrome yellow pigment meeting Federal Specification TT-P-346b, Type 111, shall be used to insure a durable finished color that complies with

Highway Yellow Color Tolerance Chart and matches Chip 33538 of Federal Standard 595. The yellow plastic shall have a minimum of 18% pigment as chrome yellow.

Glass Beads. The glass beads shall be American made, colorless and have a minimum index of refraction of 1.50 when tested using the liquid oil immersion method. The size and quality of the beads will be such that performance requirements for the retroreflective pliant polymer film shall be met.

The film shall have a glass bead retention quality such that when a 2 x 6 in. (50 x 150 mm) sample is bent over a 1/2 in. (13 mm) diameter mandrel, with the 2 in. (50 mm) dimension perpendicular to the mandrel axis, microscopic examination of the area on the mandrel shall show no more than 10% of the beads with entrapment by the binder of less than 40%.

Skid Resistance. The surface of the retroreflective pliant polymer shall provide a minimum skid resistance value of 35 BPN when tested according to ASTM E 303.

Color: ***The color of the*** *white* ***thermoplastic material shall be pure white and conform to Federal standard 595-17778. The color of the*** *yellow* ***thermoplastic material shall conform to Federal Standard 595-33538 and meet the following chromaticity specifications.***

X and **Y** coordinates shall fall in an area bordered by these coordinates:

X	**0.470**	**0.510**	**0.490**	**0.537**
Y	0.455	0.489	0.432	0.462

Reflectance. The white and yellow markings shall have the following minimum initial retroreflectance values as measured in accordance with the testing procedures of ASTM D 4061. The photometric quantity to be measured shall be specific luminance (SL) and shall be expressed as millicandelas per square foot per footcandle.

	White		**Yellow**	
Entrance Angle	86.0	86.5	86.0	86.5
Observation Angle	0.2	1.0	0.2	1.0
Specific Luminance	500	300	400	175

Thickness. The retroreflective pliant polymer film without adhesive shall be supplied in a standard thickness of 60 mils (1.5 mm).

Performance. The retroreflective pliant polymer, when applied according to the recommendations of the manufacturer, shall provide a neat, durable marking that will not flow or distort due to temperature if the pavement surface remains stable. The pliant polymer shall provide a cushioned resilient substrate that reduces bead crushing and loss. The film shall be weather resistant, and through normal traffic wear shall show no appreciable fading, lifting or shrinkage throughout the useful life of the marking. It shall also show no significant tearing, roll back or other signs of poor adhesion.

Subsection 918.09 B 3 Chemical Additives, Add the following as **Subsection B-3:**

3 Warm Mix Asphalt (WMA) additives. Organic wax or foaming additives may be added to bituminous plant mix to reduce placement temperatures in accordance with subsection 407.11. WMA additives should be introduced into the mixture at a constant rate satisfactory to produce mix temperatures as per subsection 407.11. If the proportions of the additive change during the

course of mix production, these changes shall be noted and recorded. The manner in which the additive is introduced into the mixture shall be approved by the Department. The Department will maintain a list of qualified WMA additives. No product shall be used unless it appears on this list.

Subsection 918.18-Mulch Material, Add the following as the last sentence:

"An approved tackifier from the QPL shall be used to hold mulch in place."

Subsection 918.23; Remove and Replace entire subsection with the following:

918.23- Thermoplastic Pavement Marking Material. This material shall conform to AASHTO M-249 with the following changes. The material requirements are as follows.

Composition: The retroreflective pavement marking material shall be an Alkyd / Maleic based thermoplastic material consisting of homogeneously mixed pigments, filler, resins and glass beads. The pigment, beads, and filler shall be uniformly dispersed in the resin. The material shall be manufactured from virgin material using no reprocessed components.
The material shall be free from all skins, dirt, and foreign objects and shall comply with requirements from the following table.

TABLE 1

Component	White	Yellow
% Binder Content	19.0 min	19.0 min
% TiO_2 Pigment,	10.0 min	N/A
% Intermix Glass Beads	35 min	35 min
% Calcium Carbonate \ Fillers	36 max*	46 max*

*The amount of Calcium Carbonate and inert fillers shall be as opted by the manufacturer, providing all other specifications are met.

The Titanium Dioxide shall be Rutile Type II in accordance with ASTM D 476 with a minimum purity of 93%.

Use white thermoplastic which does not contain anatase titanium dioxide pigment.

The total silica content used in the formulation of the thermoplastic shall be the premixed beads. Uniformly disperse the pigment, beads and filler in the binder.

The Alkyd / Maleic binder shall consist of a mixture of synthetic resins and high boiling point plasticizers one of, which shall be solid at room temperature. At least one-half of the binder composition shall be 100% Maleic modified glycerol ester of resin and shall be no less than 15% of the entire material formulation. The binder shall contain no petroleum, hydrocarbon resins, tall oil resins or rosins.

The thermoplastic material shall be free of contaminates and shall be dry blended or hot mixed from 100% virgin stock using no reprocessed materials.

The Thermoplastic material shall be formulated such that when it is on the roadway surface at any natural temperature it exists in a hard, solid state with cold ductility that permits normal movement with the road surface without chipping, or cracking.

The thermoplastic shall not deteriorate or discolor when held at the application temperature for periods of time up to 4 hours or upon repeated reheating (a minimum of 4 times).

The color, viscosity, and chemical properties versus temperature characteristics of the thermoplastic material shall remain constant for up to 4 hours at the application temperature and shall be the same from batch to batch.

The thermoplastic material shall be readily applicable at temperatures between 400°F and 440°F from the approved equipment to produce lines and symbols of the specified thickness above the pavement surface.

Physical Requirements: After 4 hours @ 425°F

The thermoplastic material after heating for 4 hours ± 5 minutes at 218 ± 2°C (425 ± 3°F) and cooled to 25 ± 2°C (77 ± 3°F) shall meet the physical requirements set forth in AASHTO M-249 with the following changes.

The material shall be tested in accordance with AASHTO T-250 and or with the appropriate method in Federal Test Method Standard #141 or ASTM Designation.

Safety – No toxic fumes.

Bond Strength – (ASTM-D4796), 180 p.s.i. min.

Specific Gravity – Not to exceed 2.30

Yellowness Index – The white thermoplastic shall not exceed a yellowness index of 0.15.

Glass Beads

General: All beads used for Thermoplastic Pavement Markings shall be clear, transparent, colorless glass, smooth and spherically shaped, free of milkiness, pits, or excessive air bubbles and conform to the following specific requirements.

Silica content of the glass beads shall be no less than 60%.

Color and Clarity: Beads shall be colorless, clear and free from carbon residues.

Roundness: Minimum true spheres overall shall be 80% when tested in accordance with ASTM-D-1155, for larger beads use visual inspection.

Index of Refraction: Minimum of 1.50, when tested by the liquid emersion method @ 77°F

Air Inclusions: Maximum of 3% overall

Intermix Glass Beads

Glass Beads used for intermix shall be premixed into the thermoplastic mixture and shall consist of 35% of the overall thermoplastic formulation. Intermix beads shall be uncoated and defined by two distinct gradations and meet the following requirements.

Type 1 Intermix glass beads shall comprise 50 % minimum of the 35% of the overall thermoplastic formulation (Intermix Glass Beads) and shall conform to AASHTO M-247-09, Type 1 with the exception of minimum true spheres overall shall be 80% as stated above, when tested in accordance with ASTM D-1155.

Type 3 Intermix glass beads shall comprise 50 % minimum of 35% of the overall thermoplastic formulation (Intermix Glass Beads) and shall conform to AASHTO M-247-09, Type 3 with the exception of minimum true spheres overall shall be 80% as stated above, when tested in accordance with ASTM D-1155.

Specification for Double Drop System

Double Drop on Glass Beads

General: All beads used for the **Double Drop system** for Thermoplastic Pavement Markings shall be clear, transparent, colorless glass, smooth and spherically shaped, free of milkiness, pits, or excessive air bubbles and conform to the following specific requirements.

Silica content of the glass beads shall be no less than 60%.

Color and Clarity: Beads shall be colorless, clear and free from carbon residues.

Roundness: Minimum true spheres overall shall be 80% when tested in accordance with ASTM-D-1155, for larger beads use visual inspection.

Index of Refraction: Minimum of 1.50, when tested by the liquid emersion method @ 77°F

Air Inclusions: Maximum of 3% overall

Drop on glass beads shall consist of a double drop system meeting the requirements specified herein.
The double drop system shall be capable of applying glass beads at the specified application rates. Beads shall be applied across the entire line width assuring uniform application and embedment of the beads to 50 to 60% of the bead diameter.

Type 1 drop on beads shall be dual coated for moisture resistance and adhesion , Also meet the requirements of AASHTO M-247-09 Type 1 with the exception that the beads shall be 80% round overall.
Type 4 drop on beads shall be dual coated for moisture resistance and adhesion , Also shall meet the requirements of AASHTO M-247-09 Type 4 with the exception that the beads shall be 80% round overall.

918.26-Raised Reflective Pavement Markers with Adhesive. Remove "**with Adhesive**" from the subsection title.
Subsection 918.27-Geotextile. Add "and Geosynthetics" to subsection title. **Replace** entire subsection with the following:

Geotextile and Geosynthetic materials and their types shall be on the Departments Qualified Products List. Geotextile and Geosynthetic material used shall meet the material requirements of the Standard Drawing.

The contractor shall furnish a certified laboratory test report from an approved testing laboratory and a certified letter stating the product is the same as on the Department's Qualified Products List with each shipment of materials. Laboratory test reports shall include the actual numerical test data obtained. All rolls shall be clearly labeled as being part of the same production run from which the test date was derived. Fabric shall be protected to prevent damage during transportation, storage, and installation. Geotextile and Geosynthetic rolls shall be covered during storage to protect against UV degradation and shall be stored with rolls elevated up off of the ground. Fabric that is torn, punctured, or otherwise damaged shall not be installed.

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

Contract No.	CNN489	Contractor	Benton's Construction
Project Reference No.	STP-99-3(22)	Mix Type	#56 Coarse Aggregate

T-27 RESULTS

U.S. STANDARDS SIEVES	WEIGHT RETAINED	PERCENT RETAINED	PERCENT PASSING	JMF OR SPECIFICATION
2"				
1 1/2"				
1 1/4"				
1"	40.0			
3/4"	540.0			
5/8"				
1/2"	559.0			
3/8"	1360.0			
NO. 4	1640.0			
NO. 8	1760.0			
NO. 16				
NO. 30	1950.0			
NO. 50	1960.0			
NO. 100	1970.0			
NO. 200	1980.0			
Minus #200				
TOTAL				

Homework
Monday

Material Passing #200 Sieve

T-11

ORIGINAL DRY SAMPLE WEIGHT (A)	2000.0	grams
WEIGHT OF SAMPLE AFTER WASH (B)	1990.0	grams
WASH LOSS (A-B)		grams

T-27

PAN WEIGHT (C)	1990	grams
Add'l -#200 Material (C-weight retained #200)		grams
Total Material Passing #200 Sieve		grams

Always click "Finish Editing Gradations" button after Gradations have been edited.

		1	2	3	4	5	6
Material		#56	#7	#10 (Hard)	Natural Sand	RAP	
Size		Coarse Aggregate	Medium Coarse Agg	Screenings	Natural Sand	Minus 3/4 inch Rap	
Producer and Location (As shown in TDOT's Producer Listing)		Vulcan Mtls. Clarksville, TN	Vulcan Mtls. Clarksville, TN	Vulcan Mtls. Clarksville, TN	Ingram Mtls. Clarksville, TN	Eubank Paving Clarksville, TN	
2"		100.0	100.0	100.0	100.0	100.0	
1.5"		100.0	100.0	100.0	100.0	100.0	
1.25"		100.0	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"			92.0	100.0	100.0	100.0	
3/8"			62.0	100.0	100.0	93.0	
#4			8.0	93.0	98.0	73.0	
#8			4.0	63.0	91.0	57.0	
#16						2.4	
#30			3.0	29.0	64.0	33.0	
#50			2.0	21.0	12.0	21.0	
#100			1.5	16.0	2.0	14.5	
#200			1.0	12.5	0.5	10.0	
RAP AC Content						5.1	

Homework

Monday

STATE OF TENNESSEE ASPHALT JOB MIX FORMULA

1/31/2007 V6.0

L-13. L-20

Homework
Monday

Project Ref. No.		**Date**	02/12/2009
Project No.		**Region**	3
Contract No.		**County**	Bacon Co.
Contractor		**Date of Letting**	02/06/09
State Route No.	SR-1111	**Roadway Surface**	No
Hot-mix Producer	MITCHELL'S PAVING, EAST NASHVILLE PLANT		

Type BPMB-HM **Mix** 307-BM w/ RAP PG 64-22 **Item**

Serial No.:	Design No.:

Material	Size or Grade	Producer and Location	Percent Used
#56	Coarse Aggregate	Vulcan Mtls. Clarksville, TN	47.050
#7	Medium Coarse Aggregate	Vulcan Mtls. Clarksville, TN	9.410
#10 (Hard)	Screenings	Vulcan Mtls. Clarksville, TN	23.525
RAP	Minus 3/4 inch Rap	Eubank Paving Clarksville, TN	14.874
Asphalt Cement	PG 64-22	SEM MATERIALS, PARSONS, TN	5.141

Percent AC in RAP:	5.1	**Optimum AC Content:**	5.9	**Total**	100.000
Anti-Strip Additive:	Armaz Adhere 7700/Plant			**Dosage:**	0.5%
AC Contribution:	**Virgin AC**		**RAP AC**	0.76	**Percent Virgin AC:**
Asphalt Sp. Gravity:	1.032		**Dust to Asphalt Ratio:**		

% Fracture Face on CA:	**% Glassy Particles on CA:**
Theo.Gravity of RAP:	**Eff. Gravity of Agg:**

Theo. Gravity of Mix:	**T.S.R.:**	**Lbs/Ft^3:**
L.O.I.:	**Ignition Oven Corr. Factor:**	
ADT	**Log Miles** **Beginning:**	**Ending:**

Lab Temperature		Plant Temperature	
Mixing Temperature (± 5 °F):	**300**	**Mixing Temp Range(°F):**	**290ºF ≤ T ≤ 320ºF**
Lab Compaction Temp (± 5 °F):	**280**	**Delivery Temperature(°F):**	**290ºF ≤ T ≤ 320ºF**

	Percents Used								
Sieve Size	**#56**	**#7**	**#10 (Hard)**				**RAP**	**% Req. 100**	**Design Range**
	50.0	10.0	25.0				15.0		
2"									
1.5"									
1.25"									
1"									
3/4"									
5/8"									
1/2"									
3/8"									
No.4									
No.8									
No.16									
No.30									
No.50									
No.100									
No.200									

Requested: _____ Contractor Personnel and Lab Tech Cert No.

Approved: _____ Regional Materials and Tests Supervisor

Date last lab inspection 4

Approved: _____ Headquarters Materials and Tests

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

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

Wt. Total Aggregate Blend 1500 grams

Blend Name

Contract No. CNN489

Aggregate	% Used	Wt. (gms)
1) #56	50	
2) #7	10	
3) #10 (Hard)	25	
4)		
5)		
6)		
7) RAP	15	

Homework
Monday

	Sized Fractions	% Passing	Ind. % Retained	Ind wt. Retained	Accum. wt.
	1.5"/1.25"				
	1"				
	3/4"				
1)	1/2"				
	3/8"				
	#4				
	#8				
	-#8				
	1.5"/1.25"				
	1"				
	3/4"				
	1/2"				
2)	3/8"				
	#4				
	#8				
	-#8				
	1/2"				
	3/8"				
3)	#4				
	#8				
	-#8				

4)	1/2"				
	3/8"				
	#4				
	#8				
	-#8				
5)	1/2"				
	3/8"				
	#4				
	#8				
	-#8				
6)	3/8"				
	#4				
	#8				
	#30				
	-#30				
7)	1/2"	100.0			
	3/8"				
	#4				
	#8				
	-#8				

Asphalt Liquid Calculation

Desired AC Content	Binder Weight
4.00	
4.50	
5.00	
5.50	
6.00	
6.50	

Specific Gravity and Absorption of Aggregates

AASHTO T-84 AND T-85

Blended Aggregates

From the Job Mix Formula: % Passing #4 Sieve _____

% Retained on #4 Sieve _____

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

A--Mass of Oven Dried Sample	495.0	grams
B--Mass of Flask and Water	795.0	grams
C--Mass of Flask and Water and Sample	1100.0	grams
D--Mass of Saturated Surface Dried Sample	500.1	grams

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

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

Homework

Tuesday

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

A--Mass of Oven Dried Sample	1445.0	grams
B--Mass of Saturated Surface Dried Sample	1480.0	grams
C--Mass of Sample in Water	940.0	grams

$$\text{Bulk Sp. Gr.} = \frac{A}{B - C} = _____$$

$$\text{Apparent Sp. Gr.} = \frac{A}{A - C} = _____$$

$$\%\ \text{Absorption} = \frac{B - A}{A} \times 100\% = _____\ \%$$

Combined Specific Gravity

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

Combined Bulk Specific Gravity (Gsb) _____

Combined Apparent Specific Gravity (Gsa) _____

Combined Blend Absorption _____

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

		(1)	(2)	(3)	(4)
Mass Crucible & Test Sample (before ignition)		2786.2 g	_____ g	_____ g	_____ g
Mass Crucible	(-)	1312.0 g	_____ g	_____ g	_____ g
Mass Test Sample		_____ g	_____ g	_____ g	_____ g
Mass Crucible & Test Sample (before ignition)		_____ g	_____ g	_____ g	_____ g
Mass Crucible & Test Sample (after ignition)		2498.6 g	_____ g	_____ g	_____ g
Mass Loss		_____ g	_____ g	_____ g	_____ g

Homework
Tuesday

Combined Masses from above:

Mass of Test Samples _____ g

Mass of Losses _____ g

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

% L. O. I. _____

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	365
Total No. of Particles Inspected	462

% Fractured = _____ %

Homework
Tuesday

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

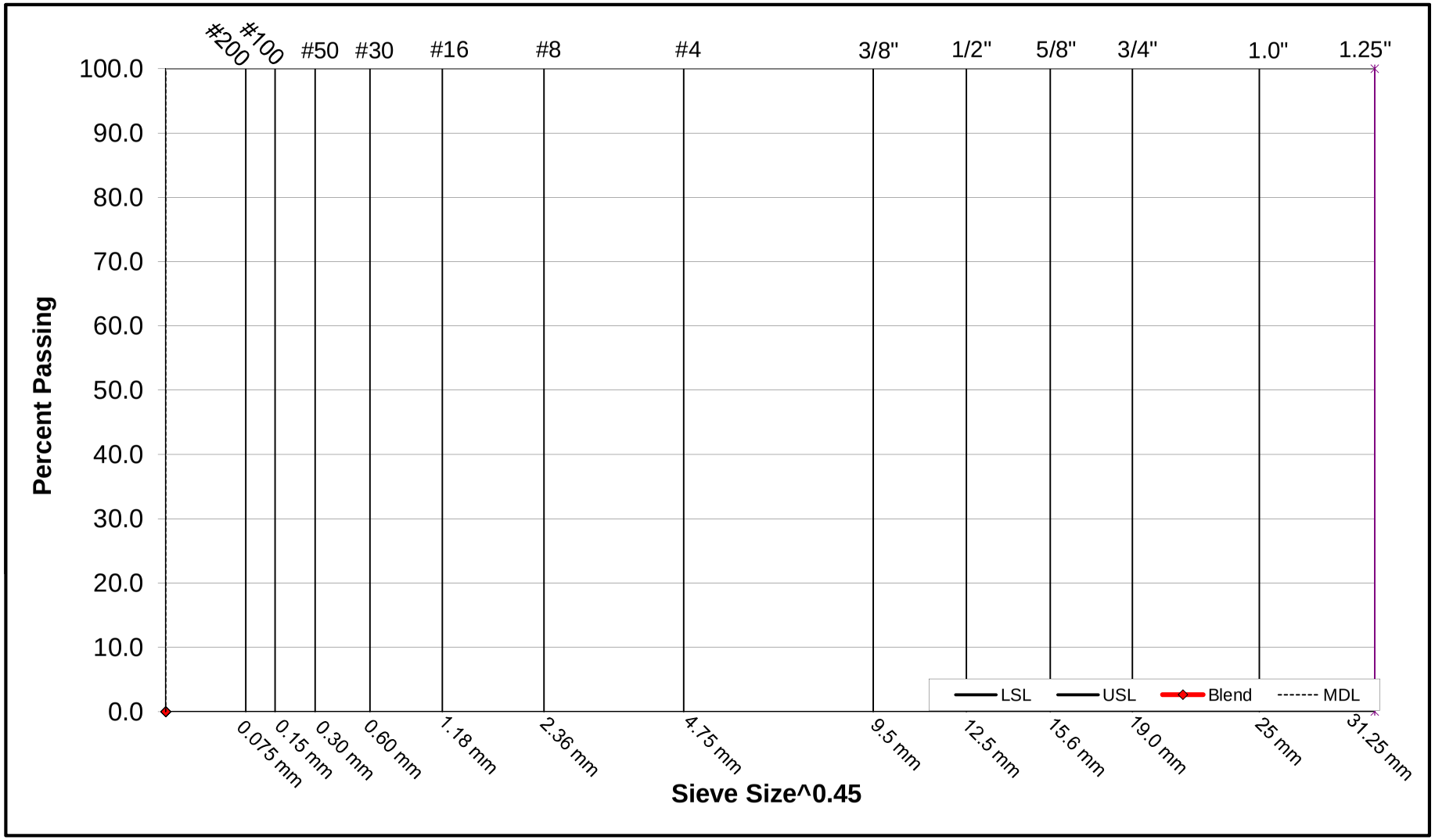
Homework

Tuesday

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

Mass of Glassy Particles	68.4	g
Total Mass of Sample Used	436.2	g

% Glassy Particles = _____ %


#200
#100
#50
#30
#16
#8
#4
3/8"
1/2"
5/8"
3/4"
1.0"
1.25"
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Percent Passing
0.075 mm
0.15 mm
0.30 mm
0.60 mm
1.18 mm
2.36 mm
4.75 mm
9.5 mm
12.5 mm
15.6 mm
19.0 mm
25 mm
31.25 mm
Sieve Size^0.45
LSL
USL
Blend
MDL

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

Project Ref. No.	STP-99-3(22)	**Date**	02/12/09
Project No.	44444-2222-11	**Region**	3
Contract No.	CNN489	**County**	Bacon Co.
Contractor	Benton's Construction	**Date of Letting**	02/06/2009
State Route No.	SR-1111		
Mix Type	307-BM w/ RAP PG 64-22		
HMA Producer	MITCHELL'S PAVING, EAST NASHVILLE PLANT		

CALCULATION OF MAXIMUM SPECIFIC GRAVITY:

		(1)	(2)	(3)
FLASK	% AC	5.9		
	WT. DRY SAMPLE + FLASK (grams)	3857.6		
	WT. FLASK (grams)	2177.0		
	WT. DRY SAMPLE (A) (grams)			
	WT. FLASK FILLED WITH WATER (D) (grams)	7391.0		
	WT. FLASK FILLED WITH WATER & DRY SAMPLE (E) (grams)	8375.2		
	MAXIMUM SPECIFIC GRAVITY MIX (G_{mm}) = $\frac{A}{A + D - E} \Rightarrow$			

CALCULATION OF THE EFFECTIVE GRAVITY OF THE AGGREGATES:

% AGGREGATES			
SPECIFIC GRAVITY OF ASPHALT CEMENT	1.032	1.032	1.032

Effective Specific Gravity of Aggregates (G_{se})

$$G_{se} = \frac{\% \text{ AGG}}{\frac{100}{G_{mm}} - \frac{\% \text{ AC}}{G_b}}$$

Avg. Effective Gravity _____

Homework
Wednesday

RICE VALUES AT OTHER ASPHALT CONTENTS

Percent Asphalt	Theoretical Maximum Density
7.0	
6.5	
6.0	
5.5	
5.0	

State of Tennessee Marshall Mix Design Sheet

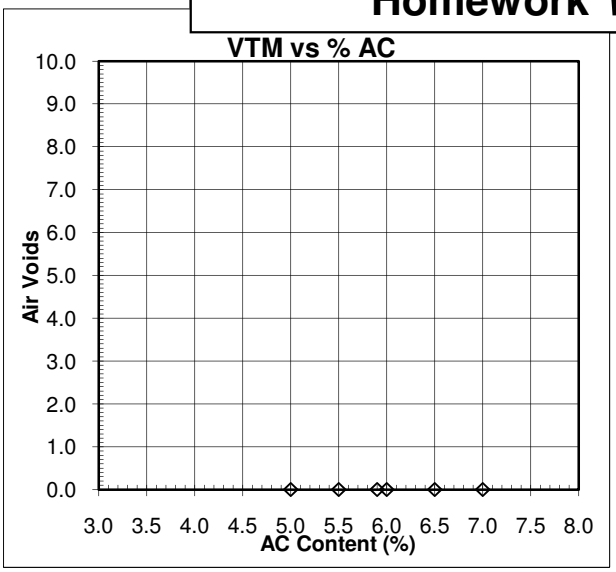
Homework
Wednesday

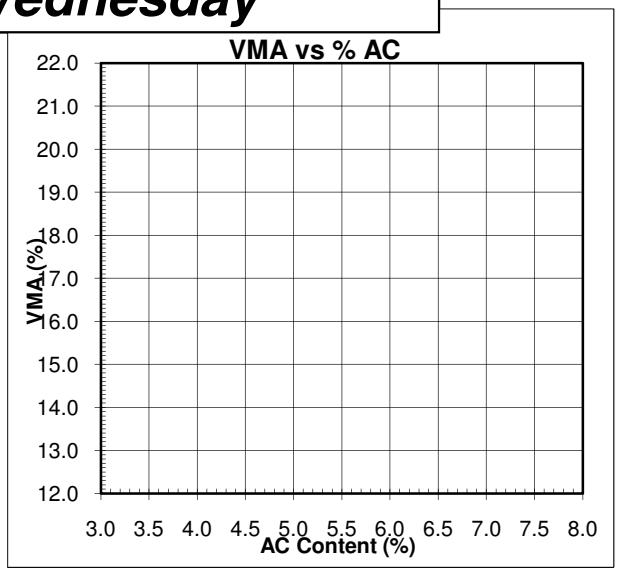
Type of Mix	307-BM w/ RAP PG 64-22	Contractor	Benton's Construction
County	Bacon Co.	Effective Gravity of Aggregate	
Project Ref. No.	STP-99-3(22)	SG of Asphalt	1.032
HMA Producer	MITCHELL'S PAVING	Number of Blows w/ Marshall Hammer	75

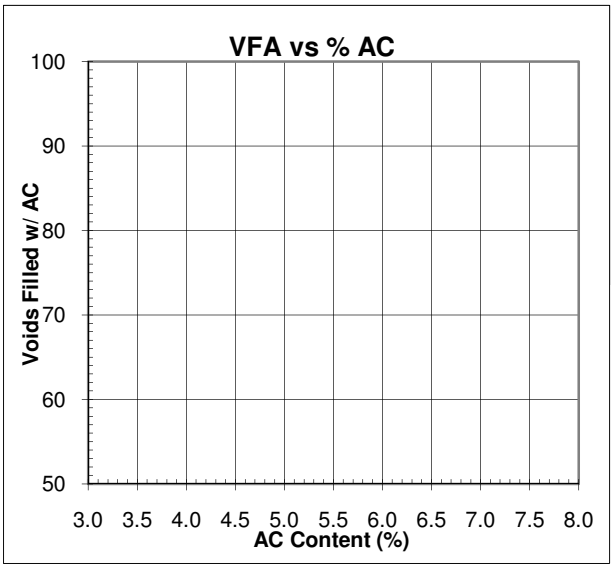
Sample No.	% AC	% Agg.	Mass (grams) In Air	SSD	In Water	Volume (ml)	Bulk SG	Rice SG or TMD	VTM (%)	VMA (%)	VFA (%)	Unit Weight (pcf)	Stability (lb)	Flow (0.01")
1-1	5.0		1157.2	1151.4	646.2								2750	10.0
1-2			1159.6	1153.9	648.7								2800	9.0
1-3			1155.8	1158.9	645.0								2850	9.0
						Avg						Avg		
2-1	5.5		1151.4	1153.9	651.3								2650	11.0
2-2			1158.2	1151.5	649.2								2700	10.0
2-3			1157.4	1159.3	650.0								2725	10.0
						Avg						Avg		
3-1	6.0		1152.2	1153.0	647.9								2625	12.0
3-2			1150.4	1151.1	648.7								2650	12.0
3-3			1141.6	1142.6	649.8								2600	12.0
						Avg						Avg		
4-1	6.5		1159.4	1150.3	650.3								2475	13.0
4-2			1151.1	1152.5	649.6								2450	12.0
4-3			1150.9	1151.6	648.9								2500	12.5
						Avg						Avg		
5-1	7.0		1157.2	1158.0	654.6								2200	13.5
5-2			1159.3	1150.1	653.8								2150	13.0
5-3			1151.0	1151.5	652.0								2075	13.5
						Avg						Avg		
Opt-1	5.9		1151.9	1152.4	655.0								2550	12.0
Opt-2			1152.4	1153.5	655.8								2600	12.0
Opt-3			1150.0	1151.2	654.6								2625	12.0
						Avg						Avg		

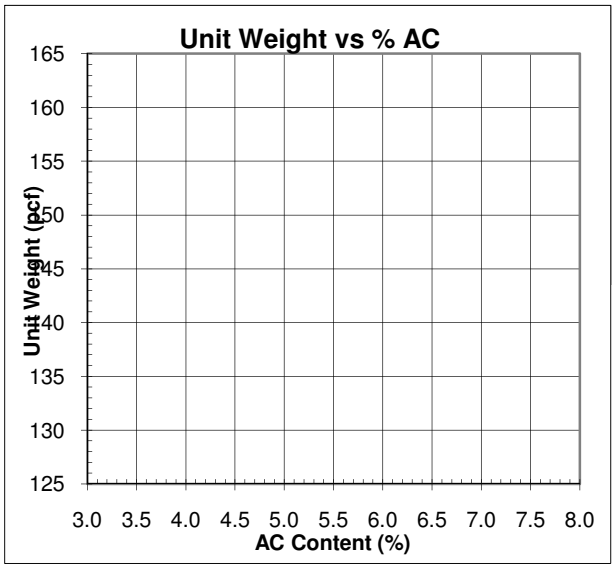
State of Tennessee Marshall Mix Design Graphs

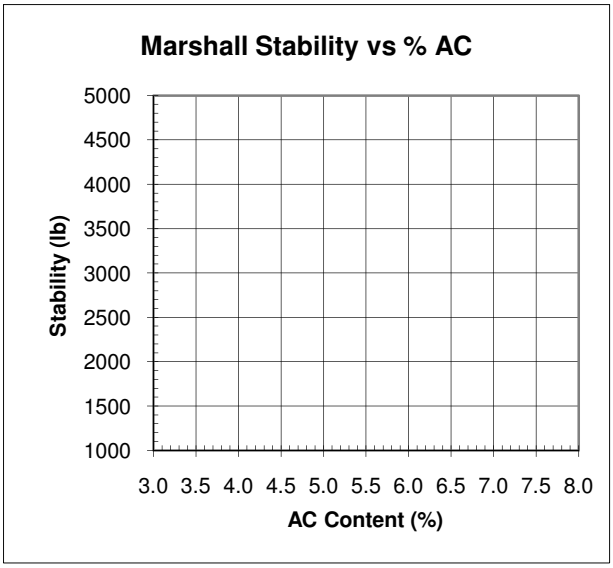
Homework *Wednesday*

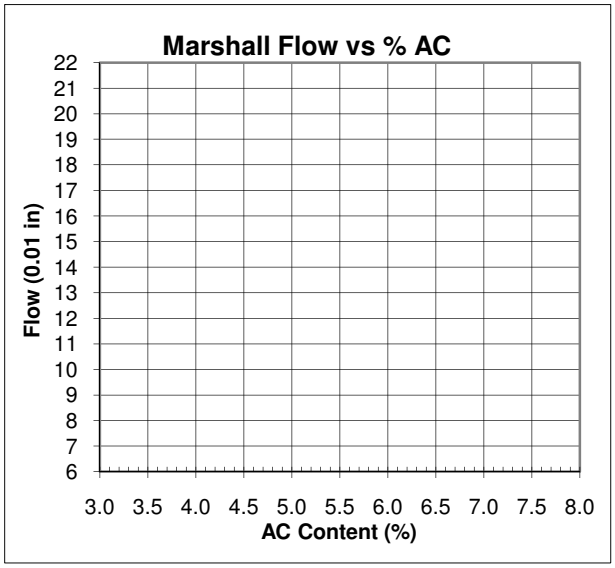




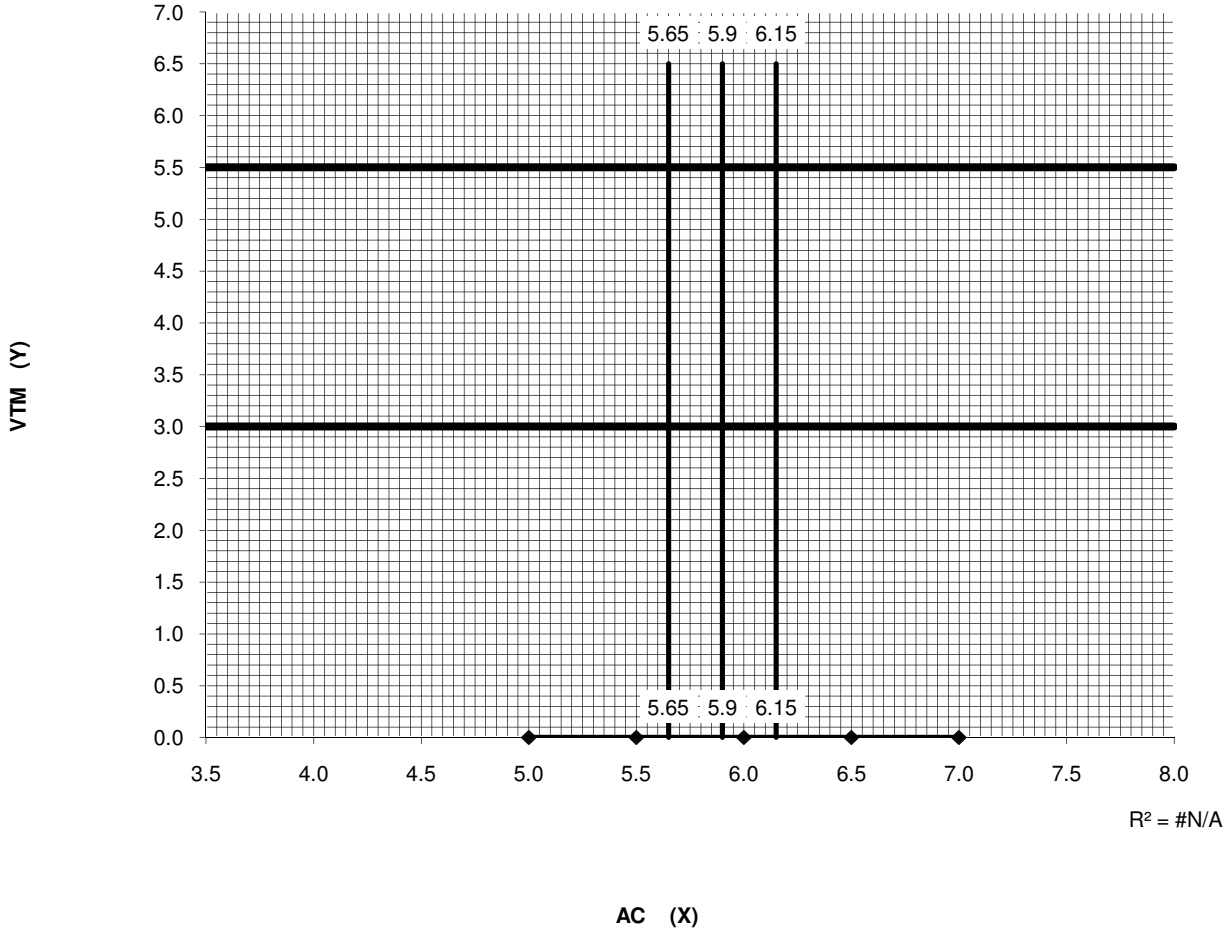








Critical Mix Graph

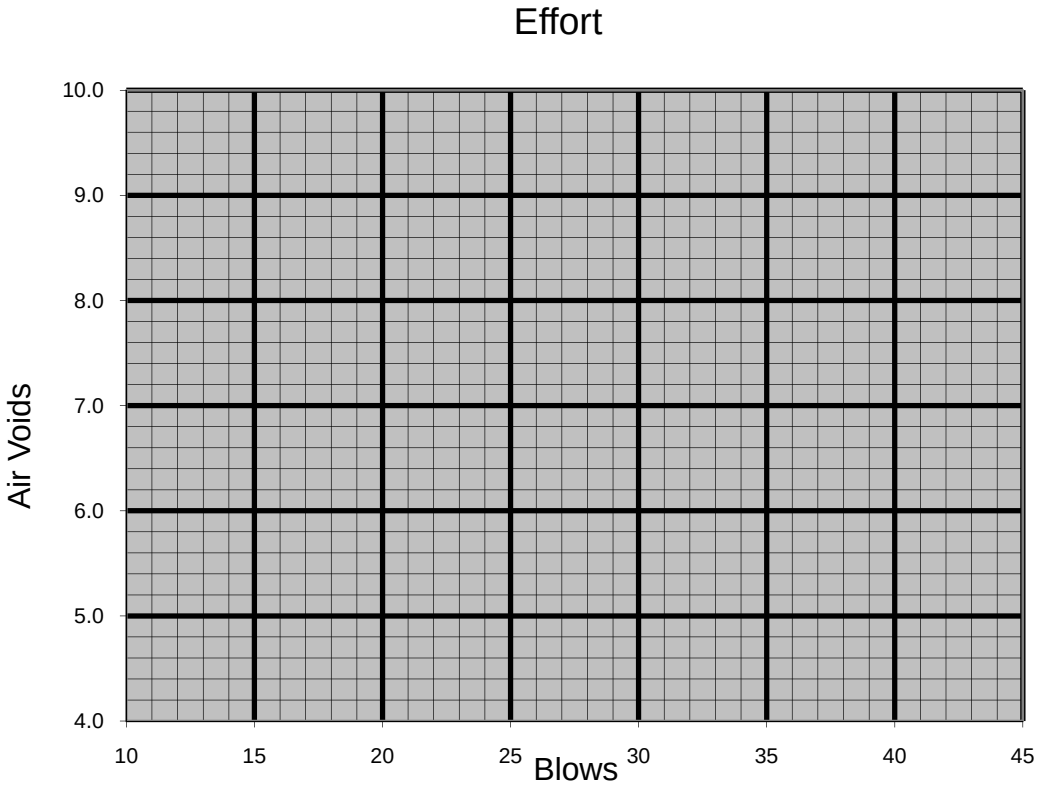


Determining Blow Count For TSR

ASTM D 4867

Lab Log #: **MD Home**

Trial Blow Effort		15	25	40
Diameter	*D*	4.0	4.0	4.0
Thickness	*T*	N/A		
Dry Mass in Air	*A*	1199.5	1199.2	1192.5
SSD Mass	*B*	1205.0	1209.2	1193.5
Mass in Water	*C*	663.2	672.0	670.2
Volume (*B-C*)	*E*			
Gmb (*A/E*)	*F*			
Gmm	*G*	2.413	2.413	2.413
% Air Voids (100(*G-F*)/*G*)	*H*			
Vol. Air Voids (*HE*/100)	*I*	N/A		



Comments:

Homework
THURSDAY

Height Adjustment Calculation

Desired Ht.	2.500
Measured Wt.	1200.0
Measured Ht.	2.600
Mtrl. Required	

Marshall Test Specimen

Homework
THURSDAY

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:

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

Example:

Initial Weight = 1200 grams

Measured Height = 2.6 inches

Adjusted weight = _____

ASTM D 4867
MOISTURE DAMAGE LABORATORY DATA SHEET

Contract No. CNN489
Mix Type 307-BM w/ RAP PG 64-22
Additive: Armaz Adhere 7700/Pla Dosage: 0.50%
Compaction Method: Marshall Hammer Effort: 28 Blows
Aggregate Effective Gravity: _____ Opt. AC content (%): 5.9
Date Tested: By:

Sample I.D.		1	2	3	4	5	6
Diameter (D)		4.00	4.00	4.00	4.00	4.00	4.00
Thickness (t)		2.50	2.50	2.50	2.50	2.50	2.50
Dry mass in air (A)		1189.4	1186.2	1187.2	1187.4	1187.4	1180.2
SSD mass (B)		1195.3	1194.5	1195.9	1195.2	1192.8	1186.3
Mass in water (C)		665.3	664.1	665.4	665.0	661.3	660.3
Volume(E)	B-C						
Bulk Sp. Gr. (F)	A/E						
Max. Sp. Gravity (G)							
% Air Void	(100(G-F)/G)						
Condition Specimen: (x)		☑	☑	☑	☐	☐	☐
Saturated	0.25	min. @		in. Hg			
SSD Mass		1211.3	1214.1	1210.3			
Degree of Saturation 55<S<80							
Conditioned 24h in 140°F water.							
Thickness (t)							
Load (P)		1915	1860	1900	2226	2200	2215
Dry (STd)	see Note 1						
Wet (STm)	see Note 1						
Results							
TSR							
Visual Moisture Damage		1					
Visual Aggregate Breakage			1				

CONDITIONED = _____ UNCONDITIONED = _____

Note 1:

$$\text{TENSILE STRENGTH (psi)} = \frac{2P}{\pi t D}$$

Homework
Thursday

DEFINITIONS

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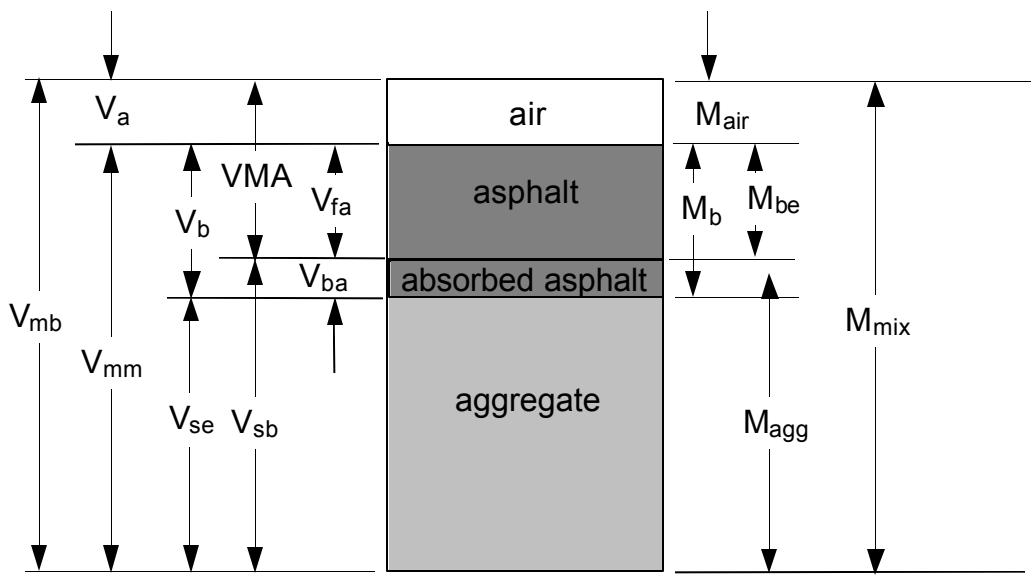
VOLUMETRIC DEFINITIONS AND FORMULAS

A factor that must be taken into account when considering asphalt mixture behavior is the *volumetric proportions* of asphalt binder and aggregate components, or more simply, *asphalt mixture volumetrics*. The volumetric properties of a compacted paving mixture [air voids (V_a), voids in the mineral aggregate (VMA), voids filled with asphalt (VFA), and effective asphalt content (P_{be})] provide some indication of the mixture's probable pavement service performance. It is necessary to understand the definitions and analytical procedures described in this chapter to be able to make informed decisions concerning the selection of the design asphalt mixture.

This chapter describes volumetric analysis of HMA, which plays a significant role in most mixture design procedures, including the Superpave system. This chapter reviews the component relationships (mass and volume, aggregate and asphalt), and presents the calculations for conducting a volumetric analysis. The information here applies to both paving mixtures that have been compacted in the laboratory, and to undisturbed samples that have been cut from a pavement in the field.

COMPONENT DIAGRAM

A tool that can assist in analyzing the properties of HMA is the component diagram -- a diagram that illustrates the individual components that make up the HMA: asphalt, aggregate and air. The simplified layout of the component diagram helps visualize the volumetric and mass



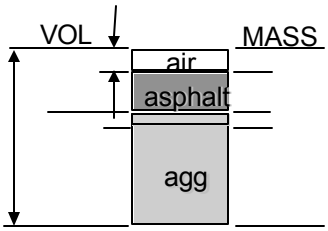
VMA = Volume of voids in mineral aggregate
V_{mb} = Bulk volume of compacted mix
V_{mm} = Voidless volume of paving mix
V_{fa} = Volume of voids filled with asphalt
V_a = Volume of air voids
V_b = Volume of asphalt binder
V_{ba} = Volume of absorbed asphalt binder
V_{sb} = Volume of mineral aggregate (by bulk specific gravity)
V_{se} = Volume of mineral aggregate (by effective specific gravity)

M = Total mass of asphalt mixture
M_b = Mass of asphalt binder
M_{be} = Mass of effective asphalt binder
M_{agg} = Mass of aggregate
M_{air} = Mass of air = 0

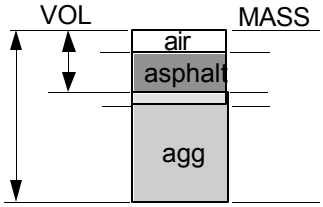
relationships that are used in the analysis of HMA.

Volumetric Properties of Asphalt Mixtures

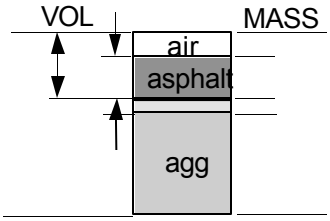
Air Voids, V_a - the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as percent of the total volume of the compacted paving mixture.



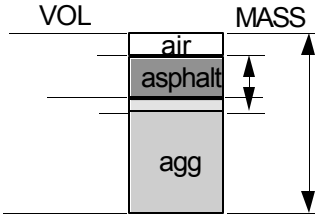
Voids in the Mineral Aggregate, VMA - the volume of intergranular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume of the compacted paving mixture.



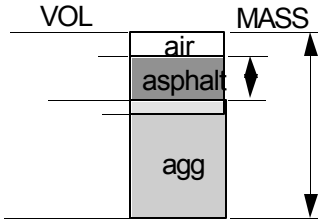
Voids Filled with Asphalt, VFA - the percentage portion of the volume of intergranular void space between the aggregate particles that is occupied by the effective asphalt. It is expressed as the ratio of (VMA - V_a) to VMA.



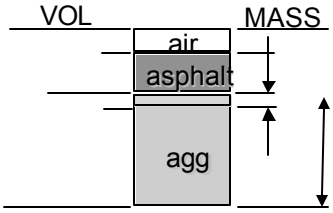
Asphalt Content, P_b - the total asphalt content of a paving mixture



Effective Asphalt Content, P_{be} - the total asphalt content of a paving mixture minus the portion of asphalt absorbed into the aggregate particles.



Absorbed Asphalt Content, P_{ba} - the portion of asphalt absorbed into the aggregate particles.



Specific Gravity

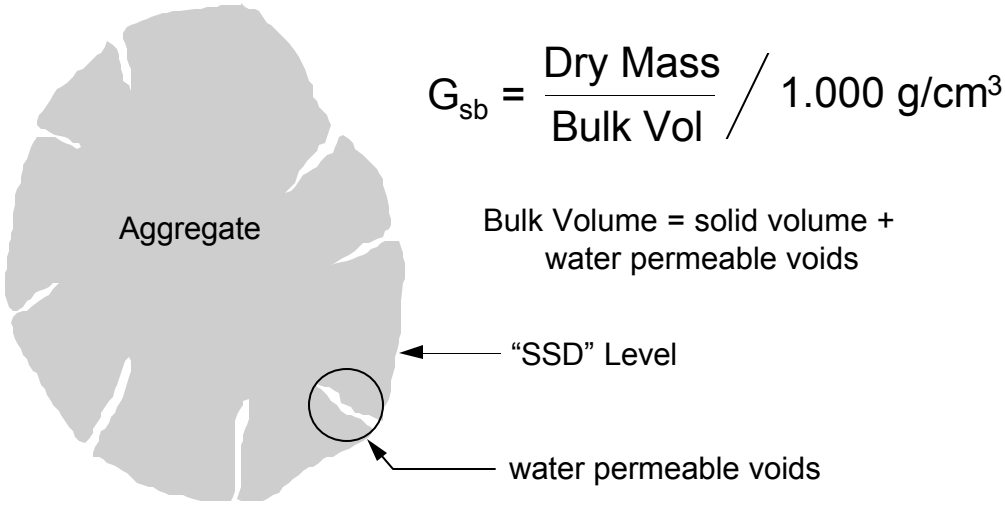
Specific gravity is "the ratio of the mass of a unit volume of a material to the mass of the same volume of water at stated temperatures." The mass of an object divided by its volume is its density, so another way to describe specific gravity is the density of an object divided by the density of water. Conveniently, at 25°C the density of water is 1.000 g/cm^3. Since the density of water is 1.000 at 25°C, the specific gravity of any object at 25°C is its weight divided by its volume. By knowing the specific gravity of an object, the volume can be calculated after measuring its mass, or the mass can be calculated after measuring its volume. Although the units for specific gravity and density are not the same, the terms are often used interchangeably. In fact, when using the metric units of g/cm^3, the values of density and specific gravity are numerically identical.

In the analysis of HMA, the specific gravities of the specific components of the HMA, as well as the specific gravities of the mixture, are used as "bridges" to go between the mass side of the component diagram and the volume side of the component diagram. Specific gravity is abbreviated using the letter G.

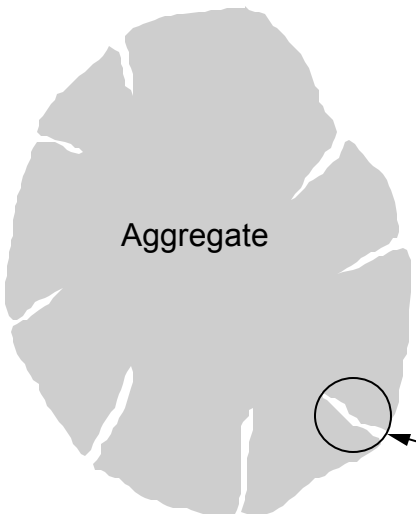
AGGREGATE SPECIFIC GRAVITIES

Mineral aggregate is porous and can absorb water and asphalt to a variable degree. Furthermore, the ratio of water to asphalt absorption varies with each aggregate. The three methods of measuring aggregate specific gravity take these variations into consideration. These methods are bulk, apparent, and effective specific gravities:

Bulk Specific Gravity, G_{sb} - the ratio of the mass in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature. In other words, the aggregate bulk specific gravity <u>includes</u> the volume of the water permeable voids in the aggregate (often termed the ""saturated surface dry" or SSD volume of the aggregate.



Apparent Specific Gravity, G_{sa} - the ratio of the mass in air of a unit volume of an impermeable material at a stated temperature to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature. In other words, the aggregate apparent specific gravity does not include the volume of the water permeable voids in the aggregate

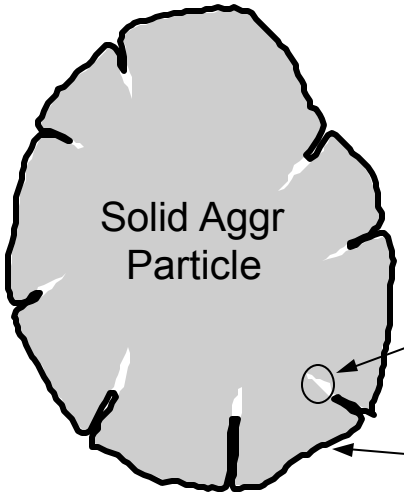


$$G_{sa} = \frac{\text{Dry Mass}}{\text{App Vol}} \Big/ 1.000\ \text{g/cm}^3$$

Apparent Volume = volume of solid aggr particle

Apparent volume does not include volume of surface pores

Effective Specific Gravity, G_{se} - the ratio of the mass in air of a unit volume of a permeable material (excluding voids permeable to asphalt) at a stated temperature to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature. In other words, the effective specific gravity includes the volume of the water permeable voids in the aggregate that cannot be reached by the asphalt.



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

Effective Volume = volume of solid aggr particle + volume of water permeable pores not filled with asphalt

volume of water permeable pores not filled with asphalt

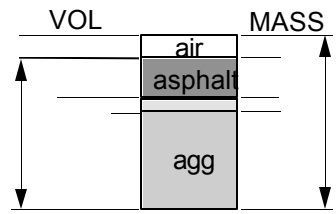
effective asphalt binder

When comparing specific gravities, the mass of the aggregate does not change; the volume does change. The bulk volume is greater than the effective volume, which is greater than the apparent volume. Since mass is divided by volume in calculating the specific gravity, G_{sa} will be larger than G_{se}, which will be larger than G_{sb}. Written symbolically, $V_{sb} > V_{se} > V_{sa}$, and $G_{sa} > G_{se} > G_{sb}$.

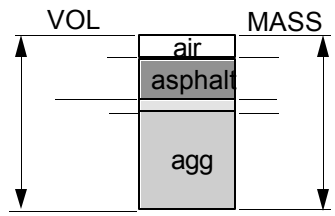
MIXTURE SPECIFIC GRAVITIES

Two measurements of the specific gravity of the HMA mixture are important in determining the volumetric properties of the HMA: the maximum theoretical specific gravity, G_{mm}, and bulk specific gravity, G_{mb}.

Maximum Theoretical Specific Gravity, G_{mm} - the ratio of the mass in air of a unit volume of the asphalt and aggregate in the mixture at a stated temperature to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature. In other words, the maximum theoretical specific gravity, G_{mm}, is the mass of the asphalt and aggregate mixture divided by the volume, not including the air voids.



Bulk Specific Gravity, G_{mb} - the ratio of the mass in air of a unit volume of the compacted asphalt and aggregate mixture at a stated temperature to the mass in air of equal density of an equal volume of gas-free distilled water at a stated temperature. In other words, the bulk specific gravity, G_{mb}, is the mass of the asphalt and aggregate mixture divided by the volume, including the air voids.



Superpave mix design calculates VMA values for compacted paving mixtures in terms of aggregate bulk specific gravity, G_{sb}. Use of other aggregate specific gravities to compute VMA means that the VMA criteria no longer apply and the mixture may not meet the requirements of Superpave. The aggregate effective specific gravity, G_{se}, should be the basis for calculating the air voids in a compacted asphalt paving mixture. **Tennessee DOT has chosen to use effective specific gravity to calculate VMA, and has changed the requirements to reflect this change.**

Voids in the mineral aggregate (VMA) and air voids (V_a) are expressed as percent by volume of the paving mixture. Voids filled with asphalt (VFA) is the percentage of VMA filled by the effective asphalt. In Superpave, the total asphalt content and the effective asphalt content are expressed as a percentage of the total mass of the paving mixture.

Because air voids, VMA and VFA are volume quantities and therefore cannot be easily measured, a paving mixture must first be designed or analyzed in terms of volumes calculated from mass measurements. For mix production purposes, these volume quantities are later changed over to mass quantities to provide a job-mix formula that can be controlled at the plant.

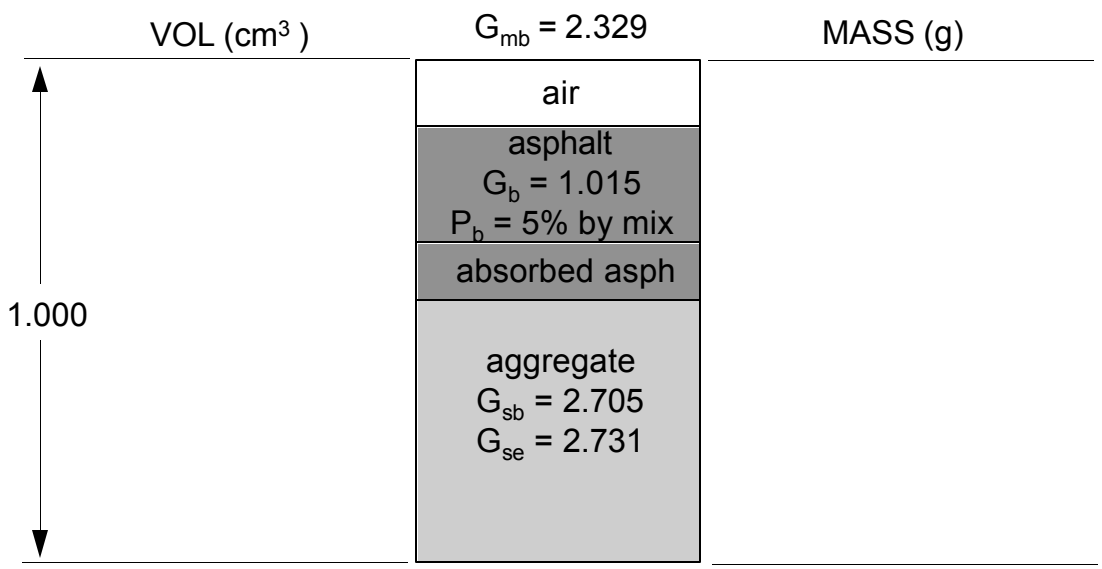
ANALYZING A COMPACTED PAVING MIXTURE

Two methods can be used to analyze the volumetric properties of compacted asphalt mixture. The first involves using the component diagram and various specific gravity measurements to calculate the relative masses and volumes of the mixture components, and then in turn calculating the volumetric properties. The second method uses the same specific gravity measurements with mathematical formulas to directly determine the mixture properties.

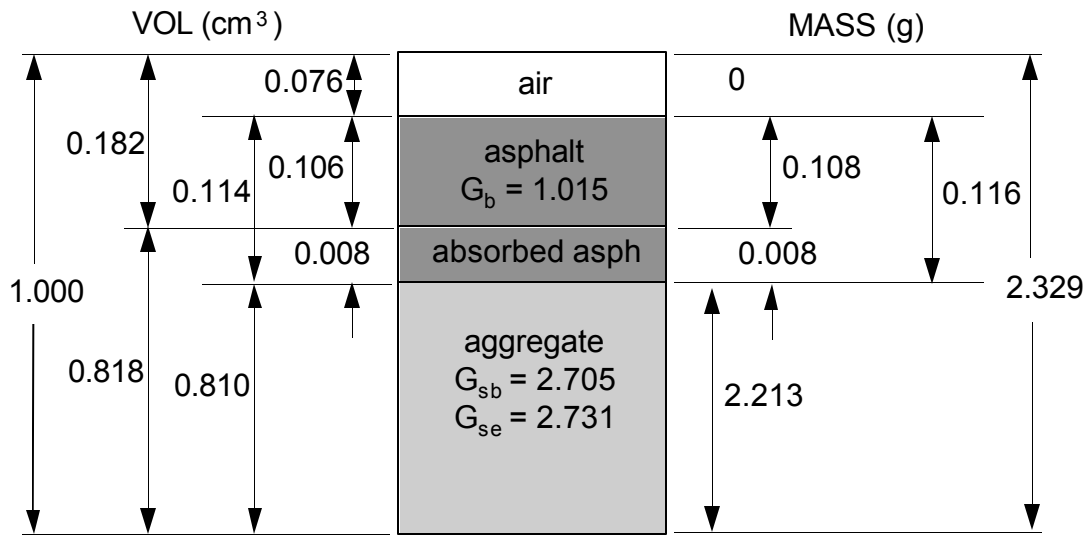
The first method is often used to illustrate the concepts behind the volumetric analysis of asphalt mixtures, and is therefore included in the presentation materials in this course. The second method, because the mathematical formulas can easily be placed into spreadsheet calculations, is more often used in laboratory mix design and analysis. These formulas are included in the text for information purposes, but are not detailed in the course presentation.

Component Diagram Method

This component diagram shows five properties (four specific gravities and the asphalt content) of a compacted specimen of HMA that have been measured at 25°C. Using only these few values, all of the volumetric properties and mass quantities of the HMA can be determined, as demonstrated in the course presentation.



These are the volumetric properties and mass quantities of this compacted specimen of HMA:



Air Voids = 7.6%
VMA = 18.2 %
VFA = 58.2 %

Effective Asphalt Content = 4.6%
Absorbed Asphalt Content = 0.4%
Max Theo Sp Grav = 2.521

Mathematical Equations Method

The measurements and calculations needed for a voids analysis are:

(a) Measure the bulk specific gravities of the coarse aggregate (AASHTO T 85 or ASTM C 127) and of the fine aggregate (AASHTO T 84 or ASTM C 128).
(b) Measure the specific gravity of the asphalt cement (AASHTO T 228 or ASTM D 70) and of the mineral filler (AASHTO T 100 or ASTM D 854).
(c) Calculate the bulk specific gravity of the aggregate combination in the paving mixture.
(d) Measure the maximum specific gravity of the loose paving mixture (ASTM D 2041 or AASHTO T209).
(e) Measure the bulk specific gravity of the compacted paving mixture (ASTM D 1188/D 2726 or AASHTO T166).
(f) Calculate the effective specific gravity of the aggregate.
(g) Calculate the maximum specific gravity at other asphalt contents.
(h) Calculate the asphalt absorption of the aggregate.
(i) Calculate the effective asphalt content of the paving mixture.
(j) Calculate the percent voids in the mineral aggregate in the compacted paving mixture.
(k) Calculate the percent air voids in the compacted paving mixture.
(l) Calculate the percent voids filled with asphalt in the compacted paving mixture

Equations for these calculations are found below.

This table provides the basic data for a sample of paving mixture. These design data are used in the sample calculations used in the remainder of this chapter.

Basic Data for Sample of Paving Mixture

Mixture Components				
	Specific Gravity		Mix Composition	
Material		Bulk	Percent by Mass of Total Mix	Percent By Mass of Total Aggregate
Asphalt Cement	1.030(G_b)		5.3 (P_b)	5.6 (P_b)
Coarse Aggregate		2.716(G_1)	47.4(P_1)	50.0(P_1)
Fine Aggregate		2.689(G_2)	47.3(P_2)	50.0(P_2)
Mineral Filler	---		---	---
Paving Mixture				
Bulk specific gravity of compacted paving mixture sample, G_{mb} = 2.442				
Maximum specific gravity of paving mixture sample, G_{mm} = 2.535				

Bulk Specific Gravity of Aggregate

When the total aggregate consists of separate fractions of coarse aggregate, fine aggregate, and mineral filler, all having different specific gravities, the bulk specific gravity for the total aggregate is calculated using:

$$G_{sb} = \frac{P_1 + P_2 + \ldots + P_N}{\frac{P_1}{G_1} + \frac{P_1}{G_2} + \ldots + \frac{P_N}{G_N}}$$

where G_{sb} = bulk specific gravity for the total aggregate
P_1, P_2, P_N = individual percentages by mass of aggregate
G_1, G_2, G_N = individual bulk specific gravities of aggregate

The bulk specific gravity of mineral filler is difficult to determine accurately. However, if the apparent specific gravity of the filler is substituted, the error is usually negligible.

Using the sample paving mixture data:

$$G_{sb} = \frac{50.0 + 50.0}{\frac{50.0}{2.716} + \frac{50.0}{2.689}} = \frac{100}{18.41 + 18.59} = 2.703$$

Effective Specific Gravity of Aggregate

When based on the maximum specific gravity of a paving mixture, G_{mm}, the effective specific gravity of the aggregate, G_{se}, includes all void spaces in the aggregate particles except those that absorb asphalt. G_{se} is determined using:

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

where G_{se} = effective specific gravity of aggregate
G_{mm} = maximum specific gravity (ASTM D 2041/AASHTO T 209) of paving mixture (no air voids)
P_{mm} = percent by mass of total loose mixture = 100
P_b = asphalt content at which ASTM D 2041/AASHTO T 209 test was performed, percent by total mass of mixture
G_b = specific gravity of asphalt

Using the sample paving mixture data:

$$G_{se} = \frac{100 - 5.3}{\frac{100}{2.535} - \frac{5.3}{1.030}} = \frac{94.7}{39.45 - 5.15} = 2.761$$

NOTE: The volume of asphalt binder absorbed by an aggregate is almost invariably less than the volume of water absorbed. Consequently, the value for the effective specific gravity of an aggregate should be between its bulk and apparent specific gravities. When the effective specific gravity falls outside these limits, its value must be assumed to be incorrect. The calculations, the maximum specific gravity of the total mix by ASTM D 2041/AASHTO T 209, and the composition of the mix in terms of aggregate and total asphalt content should then be rechecked to find the source of the error.

Maximum Specific Gravity of Mixtures with Different Asphalt Contents

In designing a paving mixture with a given aggregate, the maximum specific gravity, G_{mm}, at each asphalt content is needed to calculate the percentage of air voids for each asphalt content. While the maximum specific gravity can be determined for each asphalt content by ASTM D 2041/AASHTO T 209, the precision of the test is best when the mixture is close to the design asphalt content. Also, it is preferable to measure the maximum specific gravity in duplicate or triplicate.

After calculating the effective specific gravity of the aggregate from each measured maximum specific gravity and averaging the G_{se} results, the maximum specific gravity for any other asphalt content can be obtained using the equation shown below. The equation assumes the effective specific gravity of the aggregate is constant, and this is valid since asphalt absorption does not vary appreciably with changes in asphalt content.

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

where G_{mm} = maximum specific gravity of paving mixture (no air voids)
P_{mm} = percent by mass of total loose mixture = 100
P_s = aggregate content, percent by total mass of mixture
P_b = asphalt content, percent by total mass of mixture
G_{se} = effective specific gravity of aggregate
G_b = specific gravity of asphalt

Using the specific gravity data from the sample paving mixture data, the effective specific gravity, G_{se}, and an asphalt content, P_b, of 4.0 percent:

$$G_{mm} = \frac{100}{\frac{96.0}{2.761} + \frac{4.0}{1.030}} = \frac{100}{34.77 + 3.88} = 2.587$$

Asphalt Absorption

Absorption is expressed as a percentage by mass of aggregate rather than as a percentage by total mass of mixture. Asphalt absorption, P_{ba}, is determined using:

$$P_{ba} = 100 \times \frac{G_{se} - G_{sb}}{G_{sb} G_{se}} \times G_b$$

where P_{ba} = absorbed asphalt, percent by mass of aggregate
G_{se} = effective specific gravity of aggregate
G_{sb} = bulk specific gravity of aggregate
G_b = specific gravity of asphalt

Using the bulk and effective aggregate specific gravities determined earlier and the asphalt specific gravity from the sample paving mixture data:

$$P_{ba} = 100 \times \frac{2.761 - 2.703}{2.703 \times 2.761} \times 1.030 = 100 \times \frac{0.058}{7.463} \times 1.030 = 0.8$$

Effective Asphalt Content of a Paving Mixture

The effective asphalt content, P_{be}, of a paving mixture is the total asphalt content minus the quantity of asphalt lost by absorption into the aggregate particles. It is the portion of the total asphalt content that remains as a coating on the outside of the aggregate particles and it is the asphalt content which governs the performance of an asphalt paving mixture. The formula is:

$$P_{be} = P_b - \frac{P_{ba}}{100} \times P_s$$

where P_{be} = effective asphalt content, percent by total mass of mixture
P_b = asphalt content, percent by total mass of mixture
P_{ba} = absorbed asphalt, percent by mass of aggregate
P_s = aggregate content, percent by total mass of mixture

Using the sample paving mixture data:

$$P_{be} = 5.3 - \frac{0.8}{100} \times 94.7 = 4.5$$

Percent VMA in Compacted Paving Mixture

The voids in the mineral aggregate, VMA, are defined as the intergranular void space between the aggregate particles in a compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume. The VMA is calculated on the basis of the bulk specific gravity of the aggregate and is expressed as a percentage of the bulk volume of the compacted paving mixture. Therefore, the VMA can be calculated by subtracting the volume of the aggregate determined by its bulk specific gravity from the bulk volume of the compacted paving mixture. The calculation is illustrated for each type of mixture percentage content.

If the mix composition is determined as percent by mass of total mixture:

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

Superave Definition TDOT Definition

where VMA = voids in mineral aggregate (percent of bulk volume)
G_{sb} = bulk specific gravity of total aggregate
G_{se} = effective specific gravity of aggregate from AASHTO T 209
G_{mb} = bulk specific gravity of compacted mixture (ASTM D 1188 or D 2726/AASHTO T 166)
P_s = aggregate content, percent by total mass of mixture

Using the sample paving mixture data:

$$VMA_{bulk} = 100 - \frac{2.442 \times 94.7}{2.703} = 100 - 85.6 = 14.4$$

$$VMA_{eff} = 100 - \frac{2.442 \times 94.7}{2.761} = 100 - 83.8 = 16.2$$

Percent Air Voids in Compacted Mixture

The air voids, V_a, in the total compacted paving mixture consist of the small air spaces between the coated aggregate particles. The volume percentage of air voids in a compacted mixture can be determined using:

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

where V_a = air voids in compacted mixture, percent of total volume
G_{mm} = maximum specific gravity of paving mixture (as calculated earlier or as determined directly for a paving mixture by ASTM D 2041/AASHTO T 209)
G_{mb} = bulk specific gravity of compacted mixture

Using the sample paving mixture data:

$$V_a = 100 \times \frac{2.535 - 2.442}{2.535} = 3.7$$

Percent VFA in Compacted Mixture

The percentage of the voids in the mineral aggregate that are filled with asphalt, VFA, not including the absorbed asphalt, is determined using:

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

Superpave Definition TDOT Definition

Where, VFA = voids filled with asphalt, percent of VMA
VMA = voids in mineral aggregate, percent of bulk volume
V_a = air voids in compacted mixture, percent of total volume

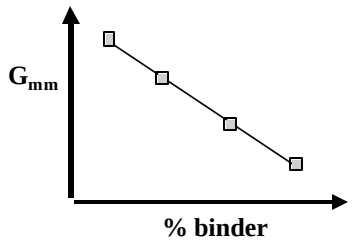
Using the sample paving mixture data:

$$VFA_{bulk} = 100 \times \frac{14.4 - 3.7}{14.4} = 74.3 \qquad VFA_{eff} = 100 \times \frac{16.2 - 3.7}{16.2} = 77.2$$

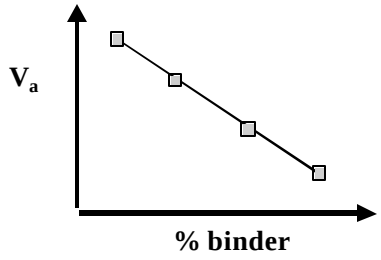
Remember, since there are two different VMA values, there are also two different VFA values

EFFECT OF CHANGING ASPHALT CONTENT ON VOLUMETRIC PROPERTIES

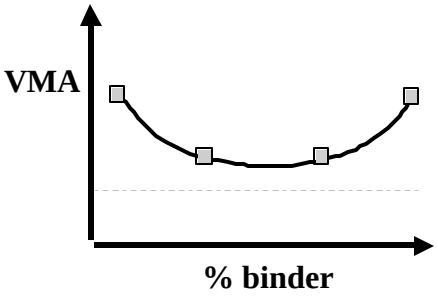
Maximum Theoretical Specific Gravity at Other Asphalt Contents



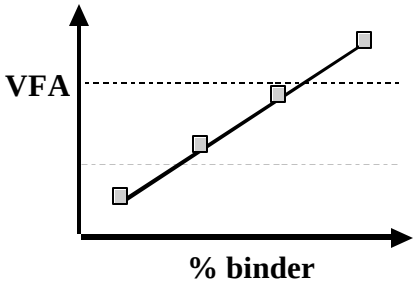
Air Void Content



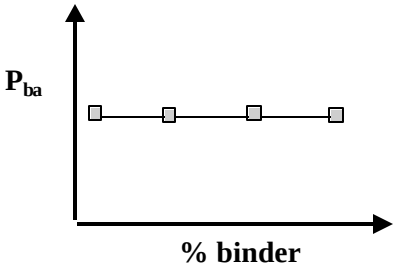
Voids in the Mineral Aggregate



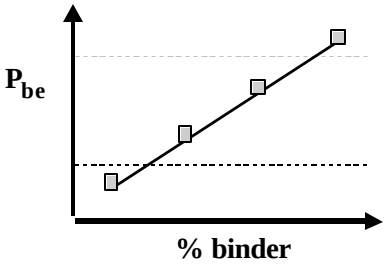
Voids Filled With Asphalt



Absorbed Asphalt Content



Effective Asphalt Content



Building Pans (Aggregate Only)

$$M_{xy} = P_x \times P_{IRy} \times M_{Tot}$$

Where M_{xy} = Mass of a given aggregate size fraction to the blended pan
P_x = Decimal Percent of that aggregate stockpile contributing to the blend.
P_{Iry} = Decimal Percent individually retained on a given sieve y.
M_{Tot} = Total blended mass of aggregate.

Building Pans (Rap)
Rap material to add to the blend.

$$M_{Rap} = \frac{P_{RAP} \times M_{Tot}}{\frac{100 - P_{bRAP}}{100}}$$

Where P_{RAP} = Decimal Percent of RAP aggregates contributing to the blend.
P_{bRAP} = Percent binder of the RAP

Asphalt to add to aggregate and RAP blends to make a HMA sample of known AC content.

$$M_{AC\,Pb} = \frac{M_{Tot}}{\frac{100 - P_b}{100}} - \frac{M_{RAP} \times P_{b\,RAP}}{100} - M_{Tot}$$

Where M_{ACPb} = Mass of asphalt at a known AC content (P_b)
M_{Tot} = Total mass of aggregate blend
M_{RAP} = Mass of RAP material added in the blend
P_{bRAP} = Percent binder in the RAP

ABBREVIATIONS

G_b	Specific Gravity of asphalt binder
G_{mb}	Bulk Specific Gravity of paving mixture
G_{mm}	Maximum Theoretical Specific Gravity of paving mixture
G_{sa}	Apparent Specific Gravity of aggregate
G_{sb}	Bulk Specific Gravity of aggregate
G_{se}	Effective Specific Gravity of aggregate
M	Total mass of asphalt mixture
M_{ACPb}	Mass of asphalt at a known AC content (P_b)
M_{agg}	Mass of aggregate
M_{air}	Mass of air = 0
M_b	Mass of asphalt binder
M_{be}	Mass of effective asphalt binder
M_{RAP}	Mass of RAP material added in the blend
M_{Tot}	Total mass of aggregate blend
M_{xy}	Mass of a given aggregate size fraction to the blended pan
P_b	Asphalt content, percent by total mass of mixture
P_{bRAP}	Percent binder of the RAP
P_{ba}	Absorbed asphalt content, percent by mass of aggregate
P_{be}	Effective asphalt content, percent by total mass of mixture
$P_{I_{ry}}$	Decimal Percent individually retained on a given sieve y
P_{mm}	Percent by mass of total loose mixture = 100
P_{RAP}	Decimal Percent of RAP aggregates contributing to the blend
P_s	Aggregate content, percent by total mass of mixture
P_x	Decimal Percent of aggregate stockpile contributing to the blend
SSD	Saturated Surface Dry
V_a	Volume of air voids, percent of total volume
V_b	Volume of asphalt binder
V_{ba}	Volume of absorbed asphalt binder
V_{fa}	Volume of voids filled with asphalt
VMA	Volume of voids in mineral aggregate
V_{mb}	Bulk Volume of compacted mix
V_{mm}	Voidless volume of paving mix
V_{sb}	Volume of mineral aggregate (by bulk specific gravity)
V_{se}	Volume of mineral aggregate (by effective specific gravity)