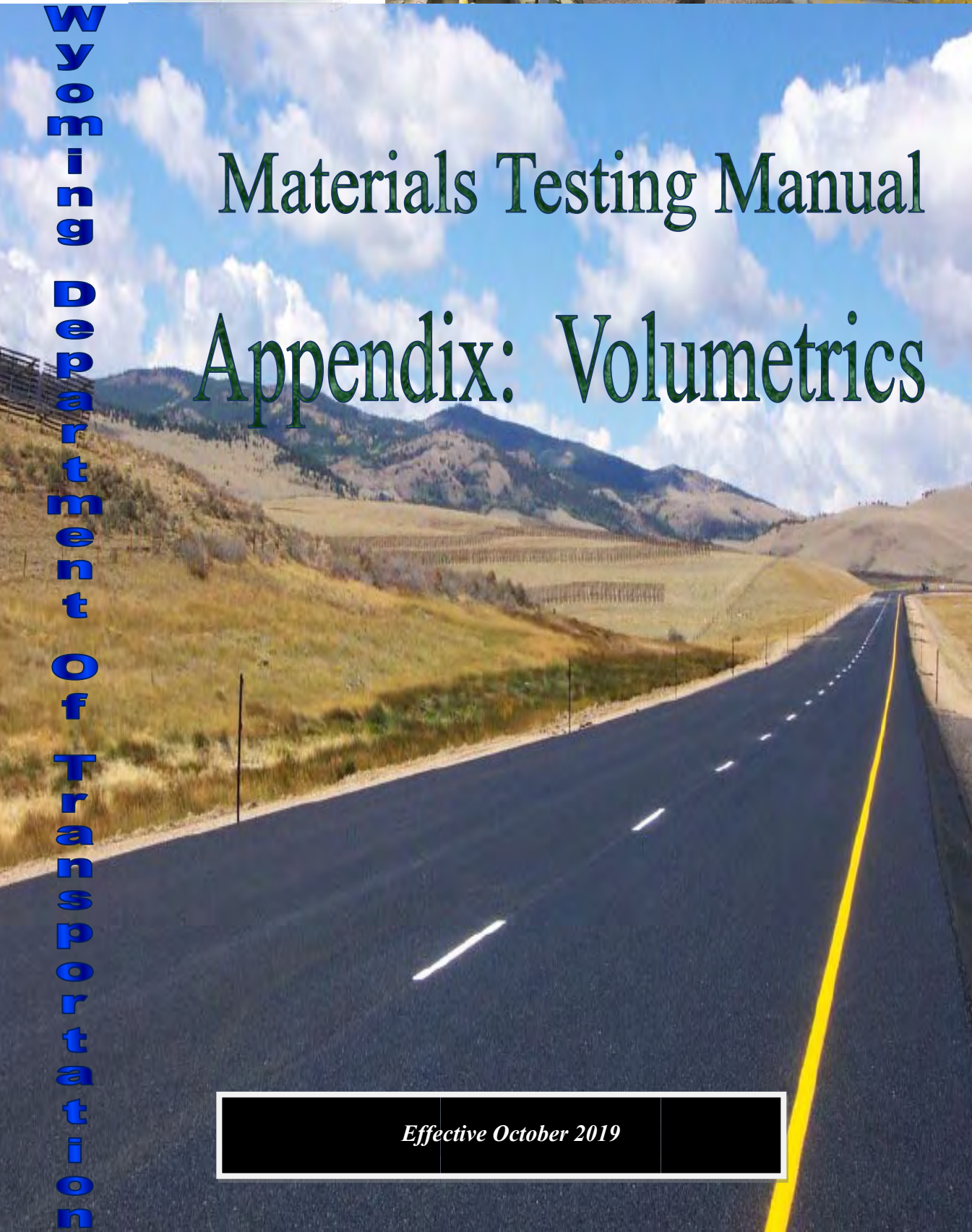




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Materials Testing Manual

Appendix: Volumetrics



Effective October 2019





**WYOMING TRANSPORTATION DEPARTMENT
 MATERIALS TESTING MANUAL VOLUMETRICS ACCEPTANCE APPENDIX
 TABLE OF CONTENTS**

The methods and procedures in this Appendix supplement and where they conflict supersede the Materials Testing Manual. They only apply to projects that have the Special Provision for High Performance Plant Mix Pavement -Volumetric Acceptance (HPPMP VA).

WYDOT No.	Last Revised	TITLE
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Print Pages

Volumetrics Acceptance (VA) Section

3 - 20	414VA.0	08-16	Superpave Laboratory Mix Design and Field Mix Volumetric Acceptance
21 - 22	415VA.0	01-18	Correlation of Volumetric Testing for Air Voids and VMA Prior to Construction
23 - 25	416VA.0	10-19	Test Strip: Correlating the Contractors' Quality Control (QC) Results
26 - 31	417VA.0	10-19	Volumetric Density Testing for Compacted Mix
32 - 36	418.1VA	10-19	Correlating the Contractors' Quality Control (QC) Voids in Mineral Aggregate (VMA) Results
37 - 41	418.2VA	10-19	Correlating the Contractors' Quality Control (QC) Air Voids (VA) Results
42 - 46	418.3VA	10-19	Correlating the Contractors' Quality Control (QC) Core Density Results
47 - 50	419.1VA	10-19	Verifying the Contractors' Quality Control (QC) Voids in Mineral Aggregate (VMA) Results
51 - 54	419.2VA	10-19	Verifying the Contractors' Quality Control (QC) Air Voids Results
55 - 59	419.3VA	10-19	Verifying the Contractors' Quality Control (QC) Core Results

VOLUMETRIC ACCEPTANCE FORMS – T-414

**Please note all MTM Forms are now accessible on the Materials Program's FTP site.
 Click on any form below and you will be directed to the FTP site to make a form selection.**

Contractors' Forms

Volumetrics Correlations Forms

Volumetrics Mainline Forms

Volumetrics Test Strip Forms

SUPERPAVE LABORATORY MIX DESIGN AND FIELD MIX VOLUMETRIC ACCEPTANCE

Scope: This procedure is similar to WYDOT 414.0, however it has been modified to generate mix designs and to perform volumetric testing of field mix per the requirements of the Special Provision for High Performance Plant Mix Pavement – Volumetric Acceptance. The Special Provision will be referred to hereafter as simply the VA specification.

Use: Mix Design - The contractor is responsible for submitting a construction mix. The laboratory and personnel performing mix design testing must be accredited. After the contractor has submitted the mix design and samples to the engineer, the engineer will review the mix design for completeness and compliance. Once the engineer has ensured that the mix design meets the contract requirements, the mix design and any associated samples will be submitted to the Materials Program.

Volumetric Acceptance during Construction - The Department and the Contractor will perform Volumetric testing in accordance with the VA specification. The sampling and testing of materials in the field for Volumetric testing will be performed by a technician trained by and working under the supervision of an AASHTO accredited lab.

Reference Documents:

AASHTO M 320	<i>Standard Specification for Performance-Graded Asphalt Binder</i>
AASHTO M 323	<i>Standard Specification for Superpave Volumetric Mix Design</i>
AASHTO R 30	<i>Standard Practice for Mixture Conditioning of Hot Mix Asphalt (HMA)</i>
AASHTO R 35	<i>Standard Practice for Superpave Volumetric Design for Hot Mix Asphalt (HMA)</i>
AASHTO T 11	<i>Standard Method of Test for Materials Finer than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing</i>
AASHTO T 27	<i>Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates</i>
AASHTO T 84	<i>Standard Method of Test for Specific Gravity and Absorption of Fine Aggregate</i>
AASHTO T 85	<i>Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate</i>
AASHTO T 100	<i>Standard Method of Test for Specific Gravity of Soils</i>
AASHTO T 164	<i>Standard Method of Test for Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)</i>

WYDOT 414VA.0
(Rev. 08-16)

AASHTO T 166	<i>Standard Method of Test for Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens</i>
AASHTO T 209	<i>Standard Method of Test for Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)</i>
AASHTO T 228	<i>Standard Method of Test for Specific Gravity of Semi-Solid Asphalt Materials</i>
AASHTO T 245	<i>Standard Method of Test for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus</i>
AASHTO T 248	<i>Standard Method of Test for Reducing Samples of Aggregate to Testing Size</i>
AASHTO T 269	<i>Standard Method of Test for Percent Air Voids in Compacted Dense and Open Asphalt Mixtures</i>
AASHTO T 283	<i>Standard Method of Test for Resistance of Compacted Hot Mix Asphalt (HMA) Mixtures to Moisture-Induced Damage</i>
AASHTO T 304	<i>Standard Method of Test for Uncompacted Void Content of Fine Aggregate</i>
AASHTO T 308	<i>Standard Method of Test for Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method</i>
AASHTO T 312	<i>Standard Method of Test for Preparing and Determining the Density of Hot Mix Asphalt (HMA) by Means of the Superpave Gyratory Compactor</i>
AI MS-2	<i>Mix Design Methods for Asphalt Concrete and Other Hot Mix Types</i>
AI SP-2	<i>Superpave Mix Design</i>
ASTM D5821	<i>Standard Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate</i>
ASTM D6995	<i>Standard Test Method for Determining Field VMA based on the Maximum Specific Gravity of the Mix (G_{mm})</i>
WYDOT 114.2	<i>WYDOT Standard Specifications</i>
WYDOT 401	<i>WYDOT Standard Specifications</i>
WYDOT 803	<i>WYDOT Standard Specifications</i>
WYDOT 414.0	<i>Marshall And Superpave Mix Design and Mix Volumetric Verification Process</i>
WYDOT 417.VA.0	<i>Volumetric Density Testing for Compacted Mix</i>
WYDOT 417.0	<i>Precision Statements for Comparing Contractor QA Results to WYDOT Verification Results</i>
WYDOT 410VA.0	<i>Sampling Plant Mix</i>
WYDOT 412VA.0	<i>Reheating Plant Mix</i>
WYDOT 419.1VA.0	<i>Verifying the Contractor's Quality Control (QC) Voids in Mineral Aggregate (VMA) Results</i>
WYDOT 418.1VA.0	<i>Correlation of Contractor and WYDOT Volumetric Testing During Construction</i>
WYDOT 803.0	<i>Aggregate Sampling and Quantity</i>
WYDOT 804.0	<i>Aggregate Sampling</i>

WYDOT 805.0	<i>Sample Splitting by Mechanical Splitter</i>
WYDOT 810.0	<i>Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate</i>
WYDOT 812.0	<i>Liquid Limit Test</i>
WYDOT 813.0	<i>Plastic Limit Test & Plasticity Index</i>
WYDOT 814.0	<i>Sieve Analysis of Combined Aggregate</i>
WYDOT 817.0	<i>Determining the Percentage of Fractured Faces in Coarse Aggregate</i>
WYDOT 818.0	<i>LA Abrasion Resistance (LAR)</i>
WYDOT 824.0	<i>Fine Aggregate Angularity</i>
WYDOT 835.0	<i>Percentage of Flat and Elongated Particles in Coarse Aggregate</i>
WYDOT 836.0	<i>Fine Aggregate Sand Equivalent</i>
WYDOT Q-12VA	<i>Milled Reclaimed Asphalt Pavement</i>
WYDOT T-158	<i>Bituminous Pavement Mix Design</i>
WYDOT T-414VA	<i>Construction Volumetric Summary Form</i>

Procedure: Mix Design

1. For Superpave mix designs, follow AASHTO R 35, AASHTO R 30, and AASHTO T 312, except where the procedures below differ. Also, for all Superpave mixes the percent air voids in laboratory mix will be 4.0 – 5.0%; and the voids in the mineral aggregate (VMA) will be in accordance with Table 2 of the VA specification.
2. Sample the aggregate for mix designs according to WYDOT 803.0.

Typically, aggregate samples for the mix design are obtained when aggregate production hits the 25 percent mark. To ensure that the gradation used for the construction mix design is representative of the material produced, ensure that the samples are representative of the average gradation of the quality control samples. If the differences exceed the allowable difference in WYDOT 417.0, re-sample the stockpile and re-run the mix design. Submit the average quality control gradation from the stockpile, the mix design gradation, and the comparison results with the mix design. Ensure that the gradation samples submitted with the mix design for the mix design verification are split samples that were obtained at the same time as the samples for the mix design.

For recycled hot plant mix (RHPM) mix designs, sample the milled reclaimed asphalt pavement (RAP). Ensure that the samples are representative of the materials to be used during construction, Section 803.5.3 *WYDOT Standard Specifications*. RAP is a variable material; the sampling program is critical to identifying the properties typical of the RAP. Milling used to produce the RAP samples for the mix design must accurately represent the production milling. Take milled RAP samples from the pavement that is typical of the entire project. It is advisable to review core data that represents the length of the project before selecting sampling locations. RAP classification is necessary to prepare a

representative mix design; a representative mix design is necessary to produce target gradation goals and achieve volumetric and density requirements. Careful sampling along with an informed selection of the target RAP gradation and asphalt content go a long way towards making construction consistent and producing a high-quality, durable pavement.

3. Determine the gradation of the coarse and fine aggregates used in the mix material according to WYDOT 814.0. The coarse material is material that is retained on a No. 4 sieve, or above. These separated materials are used in the mix design. They are generally separated on the $\frac{3}{4}$ inch, $\frac{1}{2}$ inch, $\frac{3}{8}$ inch, and the No. 4 sieves. The fine material, material passing the No. 4 screen, is analyzed for gradation according to WYDOT 814.0, but further separation for mix design batching is not required. Do this for all the aggregates used in the mix design.

Note: For some Superpave mix designs, batching the JMF gradation may be necessary to produce repeatable results. When this is determined to be necessary, indicate this on form E-46VA.

For RHPM, split each sack of RAP to ensure that the sample is representative of the entire sack. Split the material sampled from each sack according to WYDOT 805.0. Conduct an analysis of the milled RAP's gradations and asphalt content, the milling and sampling procedures, and any other factors that may influence the properties of the production milled RAP. Information about sampling, sampling locations, sampling methods, the production milling process, and data from cores should be reviewed. Consider the gradations and asphalt contents of the cores, keep in mind that cores have not gone through the milling process.

- a. Determine the asphalt content and aggregate gradation of each of the RAP sacks with a chemical extraction (AASHTO T 164). Calculate an average gradation and asphalt content for the RAP samples on Form Q-12VA.
- b. Average the extracted gradation samples from each sack to get an average RAP gradation (See example on Form Q-12VA).
- c. Select a target RAP gradation and enter it in the Target column of Form Q-12VA, using the information described in the previous paragraph. Often this will be the same as the average of the milled RAP samples. It is important that the selected target gradation and asphalt content is close to the RAP gradation and asphalt content achieved during production. This selection is critical to the creation of a mix design that will work well in the field.
 1. Select a target RAP gradation and asphalt content that is representative of the anticipated production milled RAP based on information from the milled RAP samples, the cores, and any other factors that may influence the gradation or asphalt content of the production milled RAP.

4. Determine the Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) of all fine aggregate fractions and sources using WYDOT 812.0 and WYDOT 813.0.
5. Determine the Bulk Specific Gravity of the fine and coarse aggregate for all fractions and sources using AASHTO T 84 and AASHTO T 85.
6. Determine the Los Angeles Abrasion Resistance (LAR) according to WYDOT 818.0.
7. Determine the aggregate soundness ($MgSO_4$), if necessary, according to WYDOT 810.0.
8. Determine the Fractured Faces (WYDOT 817.0), the Fine Aggregate Angularity (WYDOT 824.0), and the Flat and Elongated Particles, 1:5 (WYDOT 835.0).
9. Multiply the percentage of each aggregate type (bin split percentage) by the percentage passing for each sieve size. Add these values for each sieve size. These summed values must fall within the control points for the designated aggregate size in Table 1 of the VA specification. Narrow Band Specifications for the JMF do not apply on VA projects.

For RHPM mix designs, the combined target RAP gradation multiplied by the RAP bin split percentage from the plans when combined with the virgin JMF must fall within the control points for the designated aggregate size in Table 1 of the VA specification.

A. Batching Calculations & Examples

1. Combined Aggregate Gradations and Bin Splits

Combine the aggregate at the selected proportions (bin split percentages) or each individual sample to be compacted. In Table A1 that follows, three bin splits representing three stockpiles are to be used.

Note: The percentage (%) of each split is a starting point when developing a Job Mix Formula (JMF). Experience to achieve a gradation within specification limits is a matter of trial and error and reasoning. The No. 4 is a good starting point, normally.

Table A1. Combined Aggregate

Sieve Size	Wide Band Specifications		Bin/Stockpile Coarse Bin Splits		Fine	Combined Gradation
	Min	Max	55%	35%	10%	
1 inch	100		100	100	100	100
¾ inch	90	100	97	100	100	98
½ inch	90 Max.		41	99	100	67
No. 4			8	98	96	48
No. 8	23	49	2	70	72	33
No. 30			1	28	33	14
No. 200	2	8	0.8	8.8	16.2	5.1

Table A1 is an example of the calculations used to establish whether a particular combination of aggregates falls within the Wide Band Specifications. Nominal maximum and maximum size are controlled by the crushing operations and mix design specifications.

Table A1 from the percent passing gradation shown is a ¾ inch nominal maximum requirement, Table 803.5.5-1 *WYDOT Standard Specifications*.

Note: Aggregate gradation Wide Band is based on the nominal maximum size of the aggregate. The nominal maximum size is one size larger than the first sieve to retain more than 10 percent.

Maximum size is one sieve size larger than the nominal maximum size operations to provide an optimal mix design.

Combined gradations are calculated by multiplying the bin splits by the percentages passing each sieve. For example, on the No. 4 sieve, the combined gradation percentage passing is calculated as follows:

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

Where:

- P = Percent of combined aggregates passing a given sieve
- A, B, C, . . . = Percent of material passing a given sieve for the individual aggregates
- a, b, c, . . . = Proportion or Bin Split, of individual aggregates used in the combination, where the total = 100%

Example, No. 4:

$$(8 \times 55\%) + (98 \times 35\%) + (96 \times 10\%) = 48\%$$

Note: The combined gradation percentages are rounded to the nearest whole number.

Since all the combined gradation percentages passing are within the wide band specifications, this is an acceptable bin split for these stockpile gradations.

Simply getting the gradations within the wide band specifications does not necessarily mean a successful mix design will be achieved. Stockpile gradations and bin splits should be controlled during the crushing and mix design operations. Judgment and experience are needed to select and crush to an aggregate mixture that will result in a successful mix design.

2. Aggregate Quantities

Combine the aggregate at the bin splits determined in Table A1. Typically enough aggregate and lime will be combined to produce nine Superpave pucks and three maximum specific gravity tests samples. The quantity of material needed for each of the maximum specific gravity tests is determined according to AASHTO T 209, Section 7, Table 1 (also below).

Table 1 – Minimum Sample Sizes

Nominal Maximum Aggregate Size	Minimum Sample Size
1½ inch or greater	4,000 g
¾ inch to 1 inch	2,500 g
½ inch or smaller	1,500 g

A Superpave mix design normally requires enough material to evaluate three different asphalt contents (three Superpave specimens and one maximum specific gravity at each asphalt content). Compacted Superpave puck results should yield specimens of 2.5 ± 0.05 inches in height by 4 inches diameter, usually 1,200 g as per AASHTO T 245.

$$(1200 \text{ g} \times 9) + (2500 \text{ g} \times 3) = 18,300 \text{ g}$$

If 18,300 g of aggregate is to be used and the bin split is 55% coarse, 35% fine, and 10% filler, the following quantity from each bin would be added:

Coarse:	10,450 g
Fine:	6,650 g
Filler:	1,900 g

3. Lime Quantity

Add lime at the selected rate to the dry aggregate and completely combine by stirring, distributing it evenly throughout the aggregate. The lime percentage is expressed as a percentage of the dry weight of the aggregate. The minimum amount of lime is indicated in the Materials & Rates in the plans and is incorporated as per Section 401.1.16.1 *WYDOT Standard Specifications*.

Calculate the weight of lime to be added by multiplying the dry aggregate weight by the lime percentage addition rate. For example, with 1.0% lime and 19,000 g of dry aggregate, the lime addition of 190 g and is calculated as follows:

$$W_L = \frac{W_L \times (W_S)}{100} = \frac{1.0 \times (19,000)}{100} = 190 \text{ g}$$

Where:

P_L	=	Percentage of lime, %
W_s	=	Dry aggregate weight, g
W_L	=	Lime weight, g

4. Water Quantity

Add water at a specified water to lime ratio, expressed by weight. Add the water to evenly coat the aggregate.

Note: While doing a Job Mix Formula (JMF), a ratio of 3:1 (three parts water to one part lime) is used. This is based on Section 401.4.13.2 *WYDOT Standard Specifications*.

Calculate the weight of water to add by multiplying the weight of lime by the water: lime ratio. For example, with 190 g of lime and water: lime ratio of 3:1, the water addition rate of 570 g is calculated as follows:

$$W_W = R_{W:L} \times W_L = \frac{3}{1} \times (190) = 570 \text{ g}$$

Where:

W_W	=	Water weight, g
$R_{W:L}$	=	Water:lime ratio
W_L	=	Lime weight, g

5. Asphalt Quantity

Oven dry the aggregate/lime mixture to drive off the water. Place the batched pans in the oven and heat to a temperature not to exceed 50 °F above the mixing temperature shown in Table 2 of this section.

Add asphalt to the dry aggregate. The asphalt quantity is a percentage of the total mix weight, including the lime weight but not the water weight. Select at least three different trial asphalt contents, but none below 4.50% asphalt.

Typically three Superpave pucks and one Maximum Specific Gravity sample will be prepared at each of three asphalt contents. If one third of an aggregate and lime mixture containing 19,000 g of aggregate and 190 g of lime is mixed with 5.50% asphalt, the asphalt to be added, 372 g, is calculated as follows:

$$W_b = \frac{1}{3} (W_s + W_L) \frac{P_b}{100 - P_b}$$

$$W_b \frac{1}{3} (19,000 + 190) \frac{5.5}{100 - 5.5} = 372 \text{ g}$$

Where:

- W_b = Asphalt weight, g
- P_b = Asphalt content, %
- W_s = Dry aggregate, g

6. Mixing and Compacting

Use the asphalt binder type shown in the plans from the intended supplier. If a change to the asphalt binder type has been approved by the engineer, use the approved asphalt binder type.

Mix and compact the Superpave pucks according to AASHTO T 312, with the following modifications:

Determine the mixing and compaction temperatures for the laboratory mix design from Table 2:

Table 2. Mixing and Compacting Temperatures

	Laboratory Temperatures	
	Mixing	Compaction
	°F	°F
PG 58-28	305	280
PG 64-22	310	285
PG 64-28	315	290
PG 70-28	325	300
PG 76-28	335	310

Mixing and compaction temperatures should be determined for the asphalt grade to be supplied to the project. For example, if a PG 64-28 asphalt is to be utilized, the mixing temperature will be 315 °F and the compaction temperature will be 290 °F.

The Materials Program will provide the appropriate mixing and compaction temperatures for asphalt grades not included in Table 2.

Replace AASHTO T 312 Subsection 3.4.3 with the following:

3.4.3 Cure the specimen in accordance with AASHTO R 30 Subsection 7.1.

The design number of gyrations, N_{des} , is established by the class of mix shown in the plans and Table 401.4.13-2 *WYDOT Standard Specifications* “Marshall and Superpave Plant Mix Properties”.

B. Maximum Specific Gravity

1. Oven dry the batched aggregate-lime mixture to drive off the water. Place the batched pans in the oven and heat to a temperature not to exceed 50 °F above the mixing temperature as shown in Table 2 of this section.
2. Add asphalt to the dry aggregate. The asphalt quantity is a percentage of the total mix weight, including the lime weight but not the water weight. Use the selected trial asphalt contents. None should be below 4.50% asphalt.
3. Determine the maximum specific gravity according to AASHTO T 209, using the mix prepared as described above rather than a sample obtained as described in AASHTO T 209, Section 7.1.

C. Bulk Specific Gravity

1. Calculate the bulk unit weight by multiplying the bulk specific gravity by 62.4 to get the unit weight in pounds per cubic foot (pcf).

D. Volumetric Calculations and Examples

1. Perform the necessary calculations described as follows and report the derived values on Forms T-158 and E-46VA.

Variables: The variables here generally follow those used in the Asphalt Institute's publication MS-2, *Mix Design Methods for Asphalt Concrete and Other Hot Mix Types*.

P_1, P_2, \dots, P_n = Weight percentages of the individual aggregate portions, bin splits

P_{mm} = Total loose mixture percentage as percentage by total weight of mixture which equals 100%

- P_b = Percentage asphalt (asphalt content) as a percentage of the total mixture weight including the lime weight but not the water weight
 P_{ba} = Absorbed asphalt by weight percentage of the dry aggregate
 P_{be} = Effective asphalt content as a weight percentage of the total mixture not including the water weight
 P_s = Aggregate percentage by total weight of the mixture including the weight of the lime but not the water weight
 G_{sb} = Bulk specific gravity of the total aggregate
 G_1, G_2, \dots, G_n = Bulk specific gravities of the individual aggregate portions as determined by AASHTO T 84 & AASHTO T 85
 G_{mm} = Maximum specific gravity of the total mix, sometimes referred to as the Voidless unit weight (VUW), or the Rice specific gravity, as determined by AASHTO T 209
 G_{mb} = Bulk specific gravity of the compacted mixture as determined by AASHTO T 166
 G_{se} = Effective specific gravity of the aggregate
 G_b = Specific gravity of the asphalt, obtained from the refinery invoice or loading certificate
 V_a = Air voids, percentage, in the compacted mixture by volume
VMA = Voids in mineral aggregate (V_{ma})
VFA = Voids filled with asphalt (V_{fa})
 V_b = The volume percentage of the effective asphalt
 PP_i = Percentage passing the individual sieve
 SAF_i = Surface area factor individual sieve
SA = Surface area of the aggregate in ft²/lb
F.T. = Film thickness in μ m
D/A = Dust to asphalt ratio
 C_f = Asphalt absorption correction factor, as determined by ASTM D 6995 (this correction factor is used to calculate VMA)

Equations:

$$a. \quad G_{sb} = \frac{P_1 + P_2 + \dots + P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \dots + \frac{P_n}{G_n}} = \text{bulk specific gravity of the total aggregate}$$

$$b. \quad G_{mm} = \frac{P_{mm}}{\frac{P_s}{G_{se}} + \frac{P_b}{G_b}} = \text{maximum specific gravity (no air voids)}$$

$$c. \quad V_a = 100 \times \frac{G_{mm} - G_{mb}}{G_{mm}} = \text{air voids}$$

d.
$$G_{se} = \frac{P_{mm} - P_b}{\frac{P_{mm}}{G_{mm}} - \frac{P_b}{G_b}} = \text{effective gravity of aggregate}$$

e.
$$P_{ba} = 100 \times \frac{G_{se} - G_{sb}}{G_{sb} G_{sb}} \quad G_b = \text{absorbed asphalt}$$

f.
$$P_s = 100 - P_b = \text{aggregate percentage}$$

g.
$$P_{be} = P_b - \frac{P_{ba}}{100} \times P_a = \text{effective asphalt}$$

h.
$$\text{VMA} = 100 - \frac{G_{mb} \times P_s}{G_{sb}} = \text{voids in mineral aggregate (V}_{ma}\text{)}$$

i.
$$\text{VFA} = \frac{100 \times (\text{VMA} - V_a)}{\text{VMA}} = \text{voids filled with asphalt (V}_{fa}\text{)}$$

j.
$$V_b = \frac{P_{be} \times G_{mb}}{G_b} = \text{effective asphalt volume}$$

k.
$$\text{SA} = \sum_{i=1}^8 \frac{(\text{PP}_i) \times (\text{SAF}_i)}{100} = \text{aggregate surface area}$$

Where:
 SA = Surface area in ft²/lb
 PP_i = Percentage passing the ith sieve
 SAF_i = Surface area factor for the ith sieve

1.
$$C_f = G_{se} - G_{sb(\text{comb})}$$

Note: Report the C_f in the comments section on the E-46VA

2. Surface area is calculated by multiplying the percentage passing each indicated sieve by the surface area factor from the table below then dividing by 100. Sum these products to get the total surface area. Using the values not in parentheses gives the surface area in ft²/lb.

Table 3 SURFACE AREA FACTORS, SAF;

Total Percent Passing Sieve	Maximum Size	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200
Surface Area Factor, ft ² /lb	2	2	4	8	14	30	60	160

Note: Surface area factors shown are applicable only when all the above listed sieves are used in the sieve analysis.

Surface Area Factor for coarse aggregate (plus No. 4 sieves combined) = 2 ft²/lb

If the surface area is calculated using the surface area factors, use equation below;

$$\text{Equation m: F.T. } (\mu\text{m}) = \frac{P_{be} \times 304,800}{G_b \times (62.4) \times SA \times (100)} = \text{film thickness}$$

$$\text{Equation n: } \frac{D}{A} = \frac{PP \text{ No. } 200}{P_{be}} = \text{dust to asphalt ratio}$$

Example Data Values for Calculations:

Table 4 Test Values

- G₁ = 2.650 (from AASHTO T 84 & T 85)
- G₂ = 2.550 (from AASHTO T 84 & T 85)
- G_{mm} = 2.450 (from AASHTO T 209)
- G_{mb} = 2.300 (from AASHTO T 166)
- G_b = 1.030 (from refinery invoice or loading certificate)

Table 5 Gradation Percents Passing (PP) (from AASHTO T 27)

PP _{max}	PP _{No. 4}	PP _{No. 8}	PP _{No. 16}	PP _{No. 30}	PP _{No. 50}	PP _{No. 100}	PP _{No. 200}
100	51	41	32	24	17	10	4.8

- Selected Values:
- P₁ = 60% = (percentage from Bin 1)
 - P₂ = 40% = (percentage from Bin 2)
 - P_b = 6% = (asphalt content)

- Known Value: P_{mm} = 100%

Example Calculated Values: Substituting the data values for the variables in the equations from above are example calculations:

From Equation a.: $G_{sb} = \frac{60 + 40}{\frac{60}{2.650} + \frac{40}{2.550}} = 2.609 = \text{bulk specific gravity}$

From Equation b.: $G_{mm} = \frac{100}{\frac{94}{2.686} + \frac{6}{1.030}} = 2.450 = \text{maximum specific gravity}$

From Equation c.: $V_a = 100 \times \frac{2.450 - 2.300}{2.450} = 6.1\% = \text{air voids}$

From Equation d.: $G_{se} = \frac{100 - 6}{\frac{100}{2.450} - \frac{6}{1.030}} = 2.686 = \text{effective gravity of aggregate}$

From Equation e.: $P_{ba} = 100 \times \frac{2.686 - 2.609}{(2.609) \times (2.686)} \times 1.030 = 1.132 = \text{absorbed asphalt}$

From Equation f.: $P_s = 100 - 6.00 = 94.00\% = \text{aggregate percentage}$

From Equation g.: $P_{be} = 6.00 - \frac{1.132}{100} \times 94.00 = 4.94\% = \text{effective asphalt}$

From Equation h.: $VMA = 100 - \frac{(2.300) \times (94.00)}{2.609} = 17.1\% = \text{voids in mineral aggregate } (V_{ma})$

From Equation i.: $VFA = \frac{100(17.13 - 6.12)}{17.13} = 64\% = \text{voids filled with asphalt } (V_{fa})$

From Equation j.: $V_b = \frac{(4.94) \times (2.300)}{1.030} = 11.03\% = \text{effective asphalt volume}$

From Equation k: = aggregate surface area

$$SA = \frac{(100 \times 2) + (51 \times 2) + (41 \times 4) + (32 \times 8) + (24 \times 14) + (17 \times 30) + (10 \times 60) + (4.8 \times 160)}{100} = 29.36 \frac{\text{ft}^2}{\text{lb}}$$

Note: SAF: Surface Area Factor from Table 3.
PP: Percent passing from Table 5.

From Equation m: $F.T. (\mu\text{m}) = \frac{4.94 \times 304,800}{1.030 \times 62.4 \times 29.36 \times 100} = 8 \mu\text{m} = \text{film thickness}$

Equation n: $\frac{D}{A} = \frac{PP \text{ No.200}}{P_{be}} = \frac{4.8}{4.94} = 1.0 = \text{dust to asphalt ratio}$

10. Select the target asphalt content at which all volumetric properties meet the specified properties.
 - a. At the target asphalt content selected, determine the TSR (tensile strength ratio) in accordance with AASHTO T 283 with the following modification:
 - i. 6.6 After extraction from the molds, store the test specimens for 23 to 25 hours at room temperature, 60 °F to 86 °F.
 - a. Include the optional freeze-thaw conditioning as described in AASHTO T 283 in this method.
 - j. When the optimum asphalt content is between two trial design asphalt contents, interpolate to determine Voidless Unit Weight (VUW). This VUW will not be used during construction. A VUW for each subplot will be determined during construction in accordance with the VA specification.
 - k. Submit the complete mix design, including the T-158 and E-46VA, to the WYDOT engineer. Include all trial asphalt contents and corresponding results. Insure that the E-46 VA has been signed by the contractor, mix design representative, and Resident Engineer before submittal to the Materials Program.

Construction Mix Volumetrics:

1. For each subplot, collect cores and mix according to the VA specification and WYDOT 410VA.0. Split the samples per WYDOT 409VA.0. Reheat the mix as necessary according to WYDOT 412VA.0.
2. Test frequency will be in accordance with Table 3 (Level of Control 1 – QC/QA Testing Requirements) of the VA specification:

Note: The initial worksheets filled out by hand with the weights etc. shall be kept on file in the laboratory and will be available to the Resident Engineer at any time.

- a. Ignition Oven – Asphalt Content and Gradation
 - AASHTO T 308 and T 30
 - Determine and apply a correction factor in accordance with AASHTO T 308

- Report results to the engineer using the T-414VA
- b. Gyrotory Compactor – Compacted Density
 - AASHTO T 312
 - Reheat samples in accordance with 412VA.0
 - Compact the Superpave pucks with the N_{des} gyrations used during design
- Report results to the engineer using the T-414VA
- c. Voidless Unit Weight (VUW) – Max. Density
 - AASHTO T 209
- d. Report results to the engineer using the T-414VA
- e. Core Density (3 cores/sublot)
 - AASHTO T166, *WYDOT 415VA.0*
 - Report results to the engineer using the T-415VA Pavement Cores Worksheet

Note: Per the VA specification, VMA during production will be calculated using the method in ASTM D6995 *Standard Test Method for Determining Field VMA based on the Maximum Specific Gravity of the Mix (G_{mm})*.

Provide the engineer with the WYDOT - Volumetric Summary (VMA, V_a , In-Place Density) for each lot. These results will be evaluated by the engineer in accordance with WYDOT 418VA.0. If they are found acceptable they will be used for acceptance per the VA specification.

Provide the engineer and the Materials Program with the volumetric results using Form T-414VA and T-415VA during Construction for each lot. The T-414VA and T-415VA form is used to summarize the results for a lot. The Materials Program will incorporate the volumetric results into the permanent project file. Form T-414VA and T-415VA may be emailed to both the engineer and the Materials Program.



WYOMING DEPARTMENT OF TRANSPORTATION
BITUMINOUS PAVEMENT MIX DESIGN

Project No.: ERP Project Number Lab No.: Lab Number Aggregate: Pit Names
 Asphalt Source: Source For Use As: As Per Plans Source(s): Pit Names
 Asphalt Grade: Grade Class & Grading: Class & Grade Engineer: Resident Engineer

Sample No.	P _b	Weights, grams			Volume, cc	G _{mb}	Density, lb/ft ³	Height, inches	Stability, lbf	Flow, 0.01 in					
		Air	SSD	Wet											
1	4.5	1186.1	1190.4	683.1	507.3	2.338	145.89	2.5	3451	12					
2	P _{be}	1197.8	1201.3	688.8	512.5	2.337	145.83	2.5	3478	11					
3	2.98	1191.2	1196.1	684.3	511.8	2.327	145.20	2.5	3560	12					
D/A	1.54	VUW, lb/ft ³	159.74	V _{AC}	V _{AGGR}	V _{TOTAL}	2.334	145.64	VMA	VFA	Va				
μm	5.98	G _{mm}	2.560	6.78	84.40	91.18			15.60	43.41	8.83				
Sample No.	P _b	Weights, grams			Volume, cc	G _{mb}	Density, lb/ft ³	Height, inches	Stability, lbf	Flow, 0.01 in					
		Air	SSD	Wet											
4	5.0	1198.4	1200.6	692.8	507.8	2.360	147.26	2.5	3597	13					
5	P _{be}	1199.6	1200.5	690.3	510.2	2.351	146.70	2.5	3614	13					
6	3.57	1194.6	1196.4	689.5	506.9	2.357	147.08	2.5	3620	12					
D/A	1.29	VUW, lb/ft ³	158.18	V _{AC}	V _{AGGR}	V _{TOTAL}	2.356	147.01	VMA	VFA	Va				
μm	7.17	G _{mm}	2.535	8.20	84.75	92.95			15.25	53.70	7.06				
Sample No.	P _b	Weights, grams			Volume, cc	G _{mb}	Density, lb/ft ³	Height, inches	Stability, lbf	Flow, 0.01 in					
		Air	SSD	Wet											
7	5.5	1193.7	1194.7	693.1	501.6	2.380	148.51	2.5	3597	13					
8	P _{be}	1197.1	1197.8	695.0	502.8	2.381	148.57	2.5	3614	14					
9	4.16	1191.7	1192.5	692.0	500.5	2.381	148.57	2.5	3620	14					
D/A	1.11	VUW, lb/ft ³	156.62	V _{AC}	V _{AGGR}	V _{TOTAL}	2.381	148.55	VMA	VFA	Va				
μm	8.35	G _{mm}	2.510	9.65	85.20	94.85			14.80	65.28	5.14				
Sample No.	P _b	Weights, grams			Volume, cc	G _{mb}	Density, lb/ft ³	Height, inches	Stability, lbf	Flow, 0.01 in					
		Air	SSD	Wet											
7	6.0	1185.8	1186.6	690.4	496.2	2.390	149.14	2.5	3505	15					
8	P _{be}	1196.7	1197.2	697.3	499.9	2.394	149.39	2.5	3424	16					
9	4.74	1195.9	1196.5	699.0	497.5	2.404	150.01	2.5	3411	15					
D/A	0.97	VUW, lb/ft ³	155.19	V _{AC}	V _{AGGR}	V _{TOTAL}	2.396	149.51	VMA	VFA	Va				
μm	9.51	G _{mm}	2.487	11.07	85.28	96.35			14.72	75.14	3.66				
Sample No.	P _b	Weights, grams			Volume, cc	G _{mb}	Density, lb/ft ³	Height, inches	Stability, lbf	Flow, 0.01 in					
		Air	SSD	Wet											
	P _{be}														
D/A		VUW, lb/ft ³		V _{AC}	V _{AGGR}	V _{TOTAL}			VMA	VFA	Va				
μm		G _{mm}													
G _{sb}		2.641		G _{sa}		2.723		Water Absorption		1.15		G _b		1.026	

P_b = asphalt content by weight; P_{be} = effective asphalt content; G_{mb} = bulk specific gravity of paving mixture; G_{mm} = maximum specific gravity of paving mixture; VUW = maximum density of paving mixture; V_{AC} = volume of asphalt, %; V_{AGGR} = volume of aggregate, %; V_{TOTAL} = total volume, %; VMA = voids in mineral aggregate, %; VFA = voids filled with asphalt, %; Va = air voids; G_{sb} = bulk specific gravity of aggregate; G_{sa} = apparent specific gravity of aggregate; G_b = specific gravity of asphalt

CORRELATION OF VOLUMETRIC TESTING FOR AIR VOIDS AND VMA PRIOR TO CONSTRUCTION

Scope: This procedure compares the laboratory test methods between two laboratories results for Air voids and VMA. The comparison is performed by using the procedure in T-418VA-Air Voids and VMA: Correlating the Contractors Results.

The following laboratory test methods are compared (WYDOT 414VA.0):

- 1) Air Voids
- 2) Voids in the Mineral Aggregate (VMA)

Use: Using the procedure in T-418VA, determine if there is a significant difference between laboratories when performing the above listed test methods.

Reference Documents:

WYDOT 414VA.0	<i>Superpave Laboratory Mix Design and Field Mix Volumetric Acceptance</i>
WYDOT 418VA.0	<i>Correlating the Contractors Results</i>

Procedure: An initial results comparison will be performed prior to construction for:

1. Air Voids
2. Voids in the Mineral Aggregate (VMA)

The Materials Program will supply each lab with five split samples. Use the correlation procedure listed in T-418V; the differences in the averages between the laboratories will be used for comparison.

If the T-Critical test for 5 samples from form T-418 is exceeded, the Contractor and Department will review the test results, procedures, and laboratory equipment. If there does not appear to be any significant issues between the laboratories, the correlation will be repeated using 5 more tests.

If a successful correlation cannot be achieved, a mutually agreeable third-party will be used to evaluate the samples. If the Department results are closer to the third-party, the Contractor will pay for the third-party testing. If the Contractor results are closer to the third-party, the Department will pay for the third-party testing.

Production of plant mix cannot be approved until this correlation is completed.

WYDOT 417VA.0
(Rev. 08-16)

The % Asphalt (ignition oven) comparison will be made during construction of the test strip using mix from the three required sample locations on the test strip. The ignition oven correction factor should be determined prior to the test strip using asphalt and aggregate from the project.

TEST STRIP: CORRELATING THE CONTRACTORS QUALITY CONTROL (QC) RESULTS

Scope: This statistical procedure compares the mix (hot plant mix, recycled hot plant mix, warm plant mix) core densities, air voids, and Voids in the Mineral Aggregate (VMA) determined by WYDOT with those determined by the contractor *during the test strip*. A two-tailed paired t-test is performed on the core densities determined by the two laboratories. This procedure determines whether one can be 99 percent confident that the two laboratories are achieving different test results. This procedure will not detect minor differences between the two laboratories.

Use: This procedure determines whether densities determined by WYDOT and the contractor may be used interchangeably. If the data generated by WYDOT and the contractor are found to be significantly different, then the dispute resolution procedure will be followed.

The two-tailed paired t-test determines whether average core densities, air voids, and VMA are significantly different. The directional bias test indicates if one laboratory is getting consistently higher or lower results than the other. There is no directional bias for Air Voids and VMA on the test strip.

If there is a change in testing personnel or equipment, repeat the correlation process using production test results.

Reference

Documents: WYDOT 114 *WYDOT Standard Specifications*
WYDOT 401 *WYDOT Standard Specifications*
WYDOT 414VA *Superpave Laboratory Mix Design And Field Mix
Volumetric Acceptance*
WYDOT 417VA.0 *Volumetric Density Testing for Compacted Mix*
WYDOT T-414VA *Construction Volumetric Summary Form*
WYDOT T-417VA *Pavement Density Report*
WYDOT T-418.1VA *Correlation of VMA*
WYDOT T-418.2VA *Correlation of Air Voids*
WYDOT T-418.3VA *Correlation of Cores*

Procedure: **CORES:**

Collect 6 pairs of cores from the last 300 tons of Hot Plant Mix tons placed according to WYDOT 417VA. Per WYDOT 417VA, assign each pair a label so that pairs sampled together may be compared during the statistical analysis.

WYDOT 423.0
(Rev. 10-19)

WYDOT will compare six of their cores to the six corresponding cores of the contractors.

Determine the density of each core using WYDOT 417VA.0. Calculate and report the Percent Max Density on Form T-417VA to the nearest 0.01%.

Perform a two-tailed paired t-test on the density data as described in this section. Use the level of significance, α , of 0.02.

If any directional bias occurs, or if the t-test indicates that the two laboratories are achieving significantly different results, perform further evaluation of the correlation between the laboratories. "Directional bias" is considered to exist when all, or all but one, of the tests are higher for one laboratory than the other. "Directional bias" does not exist when at least one of the tests are less than, or equal to the corresponding paired test.

Calculations: See WYDOT 418.3VA for correlation calculations. Use 6 samples instead of 15 for the test strip.

Procedure: **AIR VOIDS and VMA**

Collect three pairs of samples from the last 300 tons of Hot Plant Mix placed according to WYDOT 410VA. Per WYDOT 414VA assign each pair a label so that pairs sampled together may be compared during the statistical analysis. WYDOT will compare 3 of their sample results to the 3 corresponding sample results of the contractors.

Determine Air Voids using WYDOT 414VA.0. Calculate and report the Air Voids on Form T-414VA to the nearest 0.1%.

Determine VMA using WYDOT 414VA.0. Calculate and report the VMA on Form T-414VA to the nearest 0.1.

Perform a two-tailed paired t-test on the VMA using procedure WYDOT 419.1VA and Air Voids using procedure WYDOT 419.2VA. Use the level of significance, α , of 0.02.

If results for air voids or VMA fail to correlate, WYDOT's results will be used for acceptance of the test strip. Re-correlate on the next lot placed.

Calculations: See WYDOT 418.1VA and 418.2VA, for correlation calculations of Air Voids and VMA. The "t critical value" for 3 pairs is 6.965.

Procedure: **% Asphalt (Ignition Oven)**

Perform the % Asphalt (ignition oven) testing in accordance with WYDOT 414VA for both WYDOT and the contractor.

The comparison will be made during construction of the test strip using mix from the three required sample locations on the test strip. If possible, the ignition oven correction factor can be determined prior to the test strip using asphalt and aggregate from the project.

Calculations: The allowable difference used for comparison of the ignition oven correction factors between the contractor and WYDOT will be 0.3.

Report: Report the results on Forms T-418.1-.3VA.

VOLUMETRIC DENSITY TESTING FOR COMPACTED MIX

Scope: This procedure describes the sequence of testing used to determine the In-Place Density of compacted mix. Included are the Coring Operation, Core Specimen testing with calculations for waxed and non-waxed specimens Specific Gravities and In-Place Density.

Apparatus:

1. Coring machine
2. Electronic scale readable to 0.1 gram; equipped with a suitable suspension apparatus and holder to permit weighing the specimen while suspended from the center of the bottom of the scale
3. Wire brush
4. Wet saw/chisel
5. Wire basket with a suspension wire of the smallest practical size to minimize any possible effects of a variable immersed length (i.e., buoyancy)
6. Container for water; 5 gal minimum, equipped with an overflow outlet for maintaining a constant water level
7. Towels
8. Convection oven
9. Tank heater

Reference Documents:

AASHTO T 166	<i>Standard Method of Test for Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens</i>
AASHTO T 275	<i>Standard Method of Test for Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Paraffin-Coated Specimens</i>
WYDOT 401.4.7.5	<i>WYDOT Standard Specifications</i>
WYDOT 401.4.8	<i>WYDOT Standard Specifications</i>
WYDOT 419VA.0	<i>Precision Statements for Comparing Contractor QA Results to WYDOT Verification Results</i>
WYDOT T-417VA	<i>Pavement Density Report</i>

Sampling: Sample locations will be randomly selected by the engineer representative using a table of random numbers in accordance with WYDOT 800VA or a random number generator, staying one foot away from the pavement ribbon edge as determined by the engineer (per section 2.2 of 401.4.7.5 of *WYDOT Standard Specifications*). If the surface texture of the test site is excessively open, or for some reason the surface will not allow testing at the identified location, another location should be selected by the engineer, staying as close as possible to the original location.

Pavement sampling will be accomplished with a coring machine. All quality

assurance (QA) testing will be performed for mix in-place density on cores.

Replace section 4.2 of AASHTO T 166 with the following:

4.2 Determine bit diameter based on the nominal maximum size of the aggregate being tested. Nominal maximum size is one size larger than the first sieve to retain more than 10 percent. If the nominal size of the aggregate is 1 inch or less, a 4 inch diameter drill bit or larger should be used.

Coring: After the finish rolling has been completed and the mat has cooled to ambient temperature, cores can be taken. If for some reason, cores are needed from the hot pavement, the area to be cored may be cooled. Blocks of dry ice or ice may be used until the internal temperature has cooled to at least 130 °F to sufficiently ensure that the sample is not distorted, bent, cracked, or has any change in its physical condition.

Note: The contractor or his representative will obtain all cores in the presence of a WYDOT inspector.

If the core is damaged, then a new core will be drilled as close as possible to the original location.

Collect two cores (contractor's acceptance and WYDOT's verification at each location in the presence of a WYDOT inspector. Mark a sample number on each core for identification later. The WYDOT inspector will keep the WYDOT's core in his/her control at all times. The contractor will separate lifts of WYDOT cores in the presence of the WYDOT inspector. Refer to Section 401.4.8 of *WYDOT Standard Specifications* and WYDOT 417VA.0 *Verifying the Contractors Quality Control (QC) Core Results* for Verification and Acceptance Procedures.

Preparation
of Samples:

Bring the core sample to room temperature at 77 ± 9 °F and clean off any foundation material such as; prime coat, soil, crushed base, or cement treated base. A stiff wire brush may facilitate cleaning.

Separate any lifts from the compacted test lift during construction of multi-lift pavements. Separation by the use of a wet saw is preferred. Care should be taken to not damage the core. The top and/or bottom of each core should then be clean of any material not part of the compacted test lift such as seal coat, tack coat, plant mix wearing course, or any foreign material such as striping tape, etc.

Insure the sample number is legible on each core for identification later. Record on Form T-417VA the sample number for each test specimen taken. Record on Form T-417VA: date sampled, station sampled, section represented, lane taken, distance from centerline, and core thickness of the compacted test lift only. Refer to example Form T-417VA of this section.

Note: Record test specimen thickness to the nearest ¼ inch measured and an average from three locations on the core.

Non-Waxed

Procedure: Use only individual weights from the desired lift for density determination. Record the core test sample weight (mass) to the nearest gram on Form T-417VA.

1. Weigh the core after the core has been immersed in water at 77 ± 1.8 °F for three to five minutes. Designate this weight as "E" on Form T-108. Each specimen will be immersed and weighed individually.

To avoid error, use the same scale to obtain all weights.

Note: Assure water level stays at optimum over flow level.

2. Weigh the Saturated Surface Dry core (SSD) in air. Designate this weight (mass) as "B" on Form T-417VA.

Remove the immersed core sample from the water. Using a damp towel blot the core until saturated surface dry (SSD), as quickly as possible not to exceed 5 seconds. Weigh the core in air on the same scale as Step 1.

A damp towel is considered when no water can be wrung from it.

Note: Any water that seeps from the test specimen during weighing is considered part of that saturated specimen (SSD).

Early in the pavement operation, check the first cores to determine if waxing is necessary (more than 2 percent absorption by volume). Continual absorption checks should be made throughout the project duration. If one core of a lot must be waxed, all cores in that lot must be tested using the wax procedure.

Note: Allow corelok with approved calibration. Corelok may be used upon engineer's acceptance of a method and calibration process.

3. Weigh the completely dried core sample in air. Designate this weight (mass) as "A" on Form T-417VA.

During testing, WYDOT and the contractor will dry the cores in a convection oven to a constant weight (mass) with a nondestructive method.

Note: If desired, the sequence of testing operation may be changed.

For example, first the dry weight "A" can be obtained and then the weight in water "E" and then the saturated surface dry weight "B". If the sequence of testing is changed and the dried core weight "A" is taken first, the core must be carefully dried in an oven at a temperature not to exceed 125 ± 5 °F so as to not cause any distortion or disintegration of the core. Drying is not complete until a constant weight is obtained (constant weight equals weight of core and does not change more than 0.05 percent when weighed at 2 hour intervals). Drying the core rapidly using excessive heat will damage the core.

Cores with visible moisture on the surface will take at least several hours to dry at 125 °F. Drying is not complete until a constant weight is obtained (i.e., weight of core changes by 0.05 percent or less between two hour intervals at this drying temperature). Turning and/or flipping the core specimen while drying may help to expose any trapped moisture.

Calculation: Calculating for dry weight;

$$\frac{(\text{Wet Weight} - \text{Dry Weight})}{(\text{Dry Weight})} \times 100 = \text{calculating for drying to 0.05 \% or less.}$$

Calculating Specific Gravity;

$$SG = \frac{A}{(B - E)} = \text{non-waxed core}$$

Example Calculating unit weight, lb/ft³

$$\text{non-waxed core UW} = \frac{A}{(B - E)} \times Cd$$

Where: SG = Specific Gravity; round to three places past the decimal
 A = Mass of sample in air after drying, g
 B = Mass of saturated surface dry (SSD) sample in air, g
 E = Mass of sample in water (wet weight), g
 Cd = 62.4 for English units lb/ft³
 UW = Unit Weight in lb/ft³

Calculating for percent Density;

$$\frac{UW}{VUW} \times 100 = \text{Percent Density}$$

Where: VUW = Voidless Unit Weight from the construction volumetric

results, lb/ft³

Note: Find the volume of water absorbed by the core, in percent, to determine if cores should be waxed. If more than two percent water is found, use the waxed procedure.

Calculating for percent of water absorbed;

$$\frac{B - A}{B - E} \times 100 = \text{Percent Water Absorbed}$$

Where: A = Mass of sample in air after drying, g
 B = Mass of saturated surface dry (SSD) sample in air, g
 E = Mass of sample in water (wet weight), g

Waxed

Procedure: This method is performed on samples with open or interconnected voids or on samples that have absorbed over 2 percent by volume as determined by steps 1 through 3 previously listed.

1. Weigh the completely dried core sample in air. Designate this weight (mass) as "A" on Form T-417VA.

The only procedure that can be used in running a wax density tests is in the order shown. Early in the pavement operation, check the first cores (as shown above) to determine if waxing is necessary and continual checks should be made throughout the project duration.

2. Put wax into a pan to be melted, have another pan full of water being heated. Place the pan with wax into the pan of hot water. To melt the wax, do not use direct heat from any kind of burner. The warm wax is ready when it is approximately 10° F above melting. Dip the core into the wax and cover all surfaces. It may be necessary to brush on melted wax to fill any pinholes left on the surface. Do not use too much wax. Allow 30 minutes to cool before weighing.

Weigh the waxed sample in air. Designate this weight (mass) as "B" on Form T-417VA.

3. Weigh the waxed sample immersed in water at 77 ± 1.8 °F. Designate the weight (mass) as "E" on Form T-108.

Each specimen will be immersed and weighed individually.

Use the same scale as used to find the weight in air.

Calculation: Calculate Specific Gravity;

$$SG = \frac{A}{(B - E) - \frac{(B - A)}{D}}$$

Example calculating unit weight, lb/ft³

$$\text{Waxed Core UW} = \frac{A}{(B - E) - \frac{(B - A)}{D}} \times Cd$$

Where:

- SG = Specific Gravity; round to three places past the decimal
- A = Mass of sample in air after drying, g
- B = Mass of waxed core sample (SSD) sample in air, g
- D = Specific gravity of the wax; round to four places past the decimal for weights
- E = Mass of waxed core sample in water (wet weight), g
- Cd = 62.4 for English units lb/ft³
- UW = Unit Weight in lb/ft³; truncate to 1 decimal place, tenth

Percent of Maximum Density;

$$\frac{UW}{VUW} \times 100 = \text{Percent Density; round to 2 decimal place}$$

Where: VUW = Voidless Unit Weight from the construction volumetric results, lb/ft³

Report: Report the specific gravity, unit weight, voidless unit weight, and percent density on Form T-417VA.

CORRELATING THE CONTRACTORS QUALITY CONTROL (QC) VOIDS IN MINERAL AGGREGATE (VMA) RESULTS

Scope: This statistical procedure compares the mix (hot plant mix, recycled hot plant mix, warm plant mix) Voids in Mineral Aggregate (VMA), determined by WYDOT with those determined by the contractor. A two-tailed paired t-test is run on the air voids determined by the two laboratories. This procedure determines whether one can be 99 percent confident that the two laboratories are achieving similar test results. This procedure will not detect minor differences between the two laboratories.

Use: This procedure determines whether densities determined by WYDOT and the contractor may be used interchangeably. If the data generated by WYDOT and the contractor are found to be significantly different, then the dispute resolution procedure will be followed.

The two-tailed paired t-test determines whether average core densities are significantly different. The directional bias test indicates if one laboratory is getting consistently higher or lower results than the other.

If there is change in testing personnel or equipment, repeat the correlation using MTM 418.1VA process using production test results.

Reference

Documents: WYDOT 114 *WYDOT Standard Specifications*
WYDOT 401 *WYDOT Standard Specifications*
WYDOT 414VA.0 *Superpave Laboratory Mix Design and Field Mix
 Volumetric Acceptance*
WYDOT T-414VA *Volumetric Summary Results for VMA and VA*
WYDOT T-418.1VA *Comparisons of VMA Volumetric Results*

Procedure: Collect one pair of samples from each subplot for all five sublots, for a total of five pairs samples according to WYDOT 410VA. Per WYDOT 414VA assign each pair a label so that pairs sampled together may be compared during the statistical analysis. WYDOT will randomly compare five of their sublots to the five corresponding sublots of the contractors. A total of five pairs of VMA samples from WYDOT and the contractor will be compared.

Determine VMA using WYDOT 414VA.0. Report the VMA on Form T-414VA to the nearest 0.1.

Perform a two-tailed paired t-test on the density data as described in this section. Use the level of significance, α , of 0.02.

If any directional bias occurs, or if the t-test indicates that the two laboratories are achieving significantly different results, perform further evaluation of the correlation between the laboratories. “Directional bias” is considered to exist when all, or all but one, of the tests are higher for one laboratory than the other. “Directional bias” does not exist when at least two of the tests are less than, or equal to the corresponding paired test.

- Calculations: 1. Calculate the difference between the five WYDOT VMA samples and the five contractor VMA samples (ensure the VMA samples from the five corresponding sublots are used) using the following equation:

$$X_i - Y_i = Z_i$$

Where: i = individual sample
 X_i = WYDOT VMA y for sample p
 Y_i = contractor VMA for sample pair i
 Z_i = difference between paired samples for sample i

2. Determine the mean (average) of the differences using the following equation:

$$\bar{Z} = \left(\frac{1}{n}\right) \sum_{i=1}^n Z_i$$

Where: \bar{Z} = mean (average) sample VMA
 n = number of samples, five in this case
 \sum = sum of unit VMA

3. Calculate the sample standard deviation¹ of the differences in VMA samples. This is done using the sample standard deviation function on a calculator or spreadsheet according to the following equation:

$$s = \sqrt{\left(\frac{1}{n-1}\right) \sum_{i=1}^n (Z_i - \bar{Z})^2}$$

Where: s = sample standard deviation

¹ On most calculators and spreadsheets there are two standard deviations, a population standard deviation and a sample standard deviation: Use the sample standard deviation. To use a calculator, first determine and record the differences, Z_i . Then calculate the standard deviation of these differences.

Paired t-test: 1. Select the appropriate value to use for s in calculating the t-test statistic:

If the sample standard deviation calculated in number 3 above is between 0.50 and 2.00, use the calculated standard deviation.

If the calculated standard deviation is less than 0.50, use $s = 0.50$.

If the calculated standard deviation is greater than 2.00, use $s = 2.00$.

2. Calculate the t-test statistic using the following equation:

$$t = \frac{|\bar{Z}|}{\sqrt{\frac{s^2}{n}}}$$

Where: t = t-test statistic
 $|\bar{Z}|$ = absolute value of the mean differences in VMA for paired samples
 s = standard deviation selected in number 1 of this section (t-tests)

3. If t is less than the critical t value, $t_{crit} = 3.747$ (used for five pairs), then the t-test does not indicate a significant difference between the WYDOT, data, X_i , and the contractor's data, Y_i .

Example: The data on Table 1 of this section is used to perform the example calculations.

1. Report the calculations on the WYDOT Form T-418.1VA.
2. Record the five VMA samples for both, WYDOT, X_i , and the contractor, Y_i .
3. Calculate the averages, Z_i .

4. Calculate the standard deviation.

Table 1: Example Data: VMA

WYDOT, X_i	Contractor, Y_i	Difference, Z_i
14.0	13.0	1.0
15.5	14.0	1.5
14.6	12.5	2.1
14.5	15.1	-0.6
13.1	13.9	-0.8

$$\text{Mean (average) } (\bar{Z}) = 0.64$$

$$\text{Standard Deviation } (s) = 1.290$$

5. Evaluate for directional bias. “Directional bias” is considered to exist when all, or all but one, of the tests are higher for one laboratory than the other. “Directional bias” does not exist when at least one of the tests are less than, or equal to the corresponding paired test. If all but one of the VMA’s determined by one laboratory is larger than the paired densities of the other laboratory, directional bias is present. To verify directional bias see “Further Evaluation” at the end of this section.

6. Calculate the value of s to determine the t-test statistic.

Since the standard deviation of 1.290 is between the minimum standard deviation of 0.5 and the maximum standard deviation of 2.00, use $s = 1.290$.

7. Calculate the t-test statistic (see number 2 of Paired t-test).

$$t = \frac{|\bar{Z}|}{\sqrt{\frac{s^2}{n}}} = \frac{0.64}{\sqrt{\frac{1.290^2}{5}}} = 1.109$$

Where: t = the t-test statistic.

8. The t-test statistic in the example is 1.109. The critical t value is 3.747 (see Note 2). Since the test statistic, 1.109, is less than the critical value, 3.747, conclude that the WYDOT data is not significantly different from the contractor's data. There is a 99 percent confidence level that the two data sets represent the same population statistically.
9. There is no directional bias since one (1) of the five (5) sample pairs had higher VMA with the WYDOT data than with the contractor data.

Since there is no directional bias, further evaluation is not needed to find the cause of the directional bias.

Further Evaluation:

1. If the average difference fails the T Critical Test, WYDOT's tests will be used and another correlation will be required. Follow Subsection 401.4.8 "*Verification*".
2. Resolve the discrepancy in accordance with Subsection 114.3.4, "*Resolving Field Test Discrepancies*".

Report: Report the results on Form T-418.1VA.

CORRELATING THE CONTRACTORS QUALITY CONTROL (QC) AIR VOIDS (VA) RESULTS

Scope: This statistical procedure compares the mix (hot plant mix, recycled hot plant mix, warm plant mix) Air Voids, determined by WYDOT with those determined by the contractor. A two-tailed paired t-test is run on the air voids determined by the two laboratories. This procedure determines whether one can be 99 percent confident that the two laboratories are achieving similar test results. This procedure will not detect minor differences between the two laboratories.

Use: This procedure determines whether densities determined by WYDOT and the contractor may be used interchangeably. If the data generated by WYDOT and the contractor are found to be significantly different, then the dispute resolution procedure will be followed.

The two-tailed paired t-test determines whether average core densities are significantly different. The directional bias test indicates if one laboratory is getting consistently higher or lower results than the other.

If there is change in testing personnel or equipment, repeat the correlation using MTM 418.2VA process using production test results.

Reference

Documents: WYDOT 114 *WYDOT Standard Specifications*
WYDOT 401 *WYDOT Standard Specifications*
WYDOT 414VA.0 *Superpave Laboratory Mix Design and Field Mix
Volumetric Acceptance*
WYDOT T-414VA *Volumetric Summary Results for VMA and VA*
WYDOT T-418.2VA *Comparisons of Volumetric Results*

Procedure: Collect one pair of samples from each subplot for all five sublots, for a total of five pairs samples according to WYDOT 410VA. Per WYDOT 414VA assign each pair a label so that pairs sampled together may be compared during the statistical analysis. WYDOT will randomly compare five of their sublots to the five corresponding sublots of the contractors. A total of five pairs of Air Voids from WYDOT and the contractor will be compared.

Determine Air Voids using WYDOT 414VA.0. Calculate and report the Air Voids on Form T-414VA to the nearest 0.1% .

Perform a two-tailed paired t-test on the density data as described in this section. Use the level of significance, α , of 0.02.

If any directional bias occurs, or if the t-test indicates that the two laboratories are achieving significantly different results, perform further evaluation of the correlation between the laboratories. “Directional bias” is considered to exist when all, or all but one, of the tests are higher for one laboratory than the other. “Directional bias” does not exist when at least one of the tests are less than, or equal to the corresponding paired test.

- Calculations: 1. Calculate the difference between the five WYDOT Air Voids and the five contractor Air Voids (ensure the Air Voids from the five corresponding sublots are used) using the following equation:

$$X_i - Y_i = Z_i$$

Where: i = individual sample
 X_i = WYDOT Air Voids for sample p
 Y_i = contractor Air Voids for sample pair i
 Z_i = difference between paired samples for sample i

2. Determine the mean (average) of the differences using the following equation:

$$\bar{Z} = \left(\frac{1}{n}\right) \sum_{i=1}^n Z_i$$

Where: \bar{Z} = mean (average) sample Air Voids
 n = number of samples, five in this case
 \sum = sum of Air Voids

3. Calculate the sample standard deviation¹ of the differences in Air Voids. This is done using the sample standard deviation function on a calculator or spreadsheet according to the following equation:

$$s = \sqrt{\left(\frac{1}{n-1}\right) \sum_{i=1}^n (Z_i - \bar{Z})^2}$$

Where: s = sample standard deviation

¹ On most calculators and spreadsheets there are two standard deviations, a population standard deviation and a sample standard deviation: Use the sample standard deviation. To use a calculator, first determine and record the differences, Z_i . Then calculate the standard deviation of these differences.

Paired t-test: 1. Select the appropriate value to use for s in calculating the t-test statistic:

If the sample standard deviation calculated in number 3 above is between 0.50 and 2.00, use the calculated standard deviation.

If the calculated standard deviation is less than 0.50, use $s = 0.50$.

If the calculated standard deviation is greater than 2.00, use $s = 2.00$.

2. Calculate the t-test statistic using the following equation:

$$t = \frac{|\bar{Z}|}{\sqrt{\frac{s^2}{n}}}$$

Where: t = t-test statistic
 $|\bar{Z}|$ = absolute value of the mean differences in Air Voids for paired samples
 s = standard deviation selected in number 1 of this section (t-tests)

3. If t is less than the critical t value, $t_{crit} = 3.747$ (used for five pairs), then the t-test does not indicate a significant difference between the WYDOT, data, X_i , and the contractor's data, Y_i .

Example: The data on Table 1 of this section is used to perform the example calculations.

1. Report the calculations on the WYDOT Form T-418.2VA.
2. Record the three air voids for both, WYDOT, X_i , and the contractor, Y_i .
3. Calculate the averages, Z_i .

4. Calculate the standard deviation.

Table 1: Example Data: Air Voids

WYDOT, X_i	Contractor, Y_i	Difference, Z_i
4.1	3.9	0.2
3.0	5.1	-2.1
3.9	4.7	-0.8
3.8	3.7	-2.1
4.0	5.0	1.0

$$\text{Mean (average) } (\bar{Z}) = 0.72$$

$$\text{Standard Deviation } (s) = 0.940$$

5. Evaluate for directional bias. “Directional bias” is considered to exist when all, or all but one, of the tests are higher for one laboratory than the other. “Directional bias” does not exist when at least two of the tests are less than, or equal to the corresponding paired test. If all but one of the densities determined by one laboratory is larger than the paired densities of the other laboratory, directional bias is present. To verify directional bias see “Further Evaluation” at the end of this section.
6. Calculate the value of s to determine the t-test statistic.

Since the standard deviation of 0.94 is between the minimum standard deviation of 0.5 and the maximum standard deviation of 2.00, use $s = 0.94$.

7. Calculate the t-test statistic (see number 2 of Paired t-test).

$$t = \frac{|\bar{Z}|}{\frac{s}{\sqrt{n}}} = \frac{|0.72|}{\frac{0.94}{\sqrt{5}}} = 1.713$$

Where: t = the t-test statistic.

8. The t-test statistic in the example is 1.713. The critical t value is 3.747 (see Note 2). Since the test statistic, 1.713, is less than the critical value, 3.747, conclude that the WYDOT data is not significantly different from the contractor's data. There is a 99 percent confidence level that the two data sets represent the same population statistically.

9. There is no directional bias since one (1) of the five (5) sample pairs had higher air voids with the WYDOT data than with the contractor data.

Since there is no directional bias, further evaluation is not needed to find the cause of the directional bias.

Further Evaluation:

1. If the average difference fails the T Critical Test, WYDOT's tests will be used and another correlation will be required. Follow Subsection 401.4.8 "*Verification*".
2. Resolve the discrepancy in accordance with Subsection 114.3.4, "*Resolving Field Test Discrepancies*".

Report: Report the results on Form T-418.2VA.

CORRELATING THE CONTRACTORS QUALITY CONTROL (QC) CORE DENSITY RESULTS

Scope: This statistical procedure compares the mix (hot plant mix, recycled hot plant mix, warm plant mix) core densities, determined by WYDOT with those determined by the contractor. A two-tailed paired t-test is run on the core densities determined by the two laboratories. This procedure determines whether one can be 99 percent confident that the two laboratories are achieving similar test results. This procedure will not detect minor differences between the two laboratories.

Use: This procedure determines whether densities determined by WYDOT and the contractor may be used interchangeably. If the data generated by WYDOT and the contractor are found to be significantly different, then the dispute resolution procedure will be followed.

The two-tailed paired t-test determines whether average core densities are significantly different. The directional bias test indicates if one laboratory is getting consistently higher or lower results than the other.

If there is change in testing personnel or equipment, repeat the correlation process using production test results.

Reference

Documents: WYDOT 114 *WYDOT Standard Specifications*
WYDOT 401 *WYDOT Standard Specifications*
WYDOT 417VA.0 *Density Testing for Compacted Mix*
WYDOT T-417VA *In Place Pavement Density Report*
WYDOT T-418.3VA *Comparisons of Volumetric Results*

Procedure: Collect three pairs of cores from each subplot for all five sublots, for a total of fifteen pairs of cores according to WYDOT 417VA. Per WYDOT 417VA assign each pair a label so that pairs sampled together may be compared during the statistical analysis. WYDOT will compare five of their sublots to the five corresponding sublots of the contractors. A total of fifteen (15) pairs of cores from WYDOT and the contractor will be compared.

Determine the density of each core using WYDOT 417VA.0. Calculate and report the Percent Max Density on Form T-417VA to the nearest 0.1 lb/ft³.

Perform a two-tailed paired t-test on the density data as described in this section.

Use the level of significance, α , of 0.02.

If any directional bias occurs, or if the t-test indicates that the two laboratories are achieving significantly different results, perform further evaluation of the correlation between the laboratories. “Directional bias” is considered to exist when all, or all but one, of the tests are higher for one laboratory than the other. “Directional bias” does not exist when at least one of the tests are less than, or equal to the corresponding paired test.

- Calculations: 1. Calculate the difference between the 15 WYDOT densities and the 15 contractor densities using the following equation:

$$X_i - Y_i = Z_i$$

Where: i = individual sample
 X_i = WYDOT core density for sample p
 Y_i = contractor core density for sample pair i
 Z_i = difference between paired samples for sample i

2. Determine the mean (average) of the differences using the following equation:

$$\bar{Z} = \left(\frac{1}{n}\right) \sum_{i=1}^n Z_i$$

Where: \bar{Z} = mean (average) sample core density
 n = number of samples, fifteen in this case
 \sum = sum of unit densities

3. Calculate the sample standard deviation¹ of the differences in core densities. This is done using the sample standard deviation function on a calculator or spreadsheet according to the following equation:

$$s = \sqrt{\left(\frac{1}{n-1}\right) \sum_{i=1}^n (Z_i - \bar{Z})^2}$$

Where: s = sample standard deviation

¹ On most calculators and spreadsheets there are two standard deviations, a population standard deviation and a sample standard deviation: Use the sample standard deviation. To use a calculator, first determine and record the differences, Z_i . Then calculate the standard deviation of these differences.

Paired t-test: 1. Select the appropriate value to use for s in calculating the t-test statistic:

If the sample standard deviation calculated in number 3 above is between 0.50 and 2.00, use the calculated standard deviation.

If the calculated standard deviation is less than 0.50, use $s = 0.50$.

If the calculated standard deviation is greater than 2.00, use $s = 2.00$.

2. Calculate the t-test statistic using the following equation:

$$t = \frac{|\bar{Z}|}{\sqrt{\frac{s^2}{n}}}$$

Where: t = t-test statistic
 $|\bar{Z}|$ = absolute value of the mean differences in density for paired samples
 s = standard deviation selected in number 1 of this section (t-tests)

3. If t is less than the critical t value, $t_{crit} = 2.624$ (used for fifteen pairs), then the t-test does not indicate a significant difference between the WYDOT, data, X_i , and the contractor's data, Y_i .

4. Evaluate for directional bias. "Directional bias" is considered to exist when all, or all but one, of the tests are higher for one laboratory than the other. "Directional bias" does not exist when at least two of the tests are less than, or equal to the corresponding paired test. If all but one of the densities determined by one laboratory is larger than the paired densities of the other laboratory, directional bias is present. To verify directional bias see "Further Evaluation" at the end of this section.

Example: The data on Table 1 of this section is used to perform the example calculations.

1. Report the calculations on the WYDOT Form T-418.3VA.
2. Record the fifteen (15) unit weights for both, WYDOT, X_i , and the contractor, Y_i .
3. Calculate the averages, Z_i .
4. Calculate the standard deviation.

Table 1: Example Data: Core Densities, lb/ft³

WYDOT, X_i	Contractor, Y_i	Difference, Z_i
141.4	140.9	0.5
142.3	141.7	0.6
140.7	140.8	-0.1
141.6	141.4	0.2
142.1	141.6	0.5
141.0	140.4	0.6
142.0	142.4	-0.4
142.4	141.9	0.5
140.5	140.4	0.1
141.7	141.1	0.6
142.0	141.7	0.3
141.5	142.1	-0.6
142.3	142.0	0.3
142.5	141.8	0.7
140.4	140.2	0.2

$$\text{Mean (average) } (\bar{Z}) = 0.27$$

$$\text{Standard Deviation } (s) = 0.380$$

5. Calculate the value of s to determine the t-test statistic.

Since the standard deviation of 0.380 is less than the minimum standard deviation of 0.50, use $s = 0.50$.

6. Calculate the t-test statistic (see number 2 of Paired t-test).

$$t = \frac{|\bar{Z}|}{\sqrt{\frac{s^2}{n}}} = \frac{|0.27|}{\sqrt{\frac{0.50^2}{15}}} = 2.091$$

Where: t = the t-test statistic.

7. The t-test statistic in the example is 2.091. The critical t value is 2.624 (see Note 2). Since the test statistic, 2.091, is less than the critical value, 2.624, conclude that the WYDOT data is not significantly different from the contractor's data. There is a 99 percent confidence level that the two data sets represent the same population statistically.
8. There is no directional bias since twelve (12) of the fifteen (15) sample pairs had higher densities with the WYDOT data than with the contractor data.

Since there is no directional bias, further evaluation is not needed to find the cause of the directional bias.

Further Evaluation:

1. If the average difference fails the T Critical Test, WYDOT's tests will be used and another correlation will be required. Follow Subsection 401.4.8 "*Verification*".
2. Resolve the discrepancy in accordance with Subsection 114.3.4, "*Resolving Field Test Discrepancies*".
3. For Informational Purposes Only:

WYDOT and Contractors swap cores and observe QC testing.

Report: Report the results on Form T-418.3VA.

VERIFYING THE CONTRACTORS QUALITY CONTROL (QC) VOIDS IN MINERAL AGGREGATE (VMA) RESULTS

Scope: This statistical procedure compares the mix (hot plant mix, recycled hot plant mix, warm plant mix) Voids in Mineral Aggregate (VMA), determined by WYDOT with those determined by the contractor. A two-tailed paired t-test is run on the air voids determined by the two laboratories. This procedure determines whether one can be 99 percent confident that the two laboratories are achieving similar test results. This procedure will not detect minor differences between the two laboratories.

Use: This procedure determines whether densities determined by WYDOT and the contractor may be used interchangeably. If the data generated by WYDOT and the contractor are found to be significantly different, then the dispute resolution procedure will be followed.

The two-tailed paired t-test determines whether average VMA's are significantly different.

If there is change in testing personnel or equipment, repeat the correlation using MTM 418.1VA process using production test results.

Reference

Documents: WYDOT 114 *WYDOT Standard Specifications*
WYDOT 401 *WYDOT Standard Specifications*
WYDOT 410VA *Sampling Plant Mix*
WYDOT 414VA.0 *Superpave Laboratory Mix Design and Field Mix
Volumetric Acceptance*
WYDOT T-414VA *Volumetric Summary Results for VMA and VA*
WYDOT T-419.1VA *Comparisons of Volumetric Results*

Procedure: Collect one pair of samples from each subplot for all five sublots, for a total of five pairs of samples according to WYDOT 410VA. Per WYDOT 414VA assign each pair a label so that pairs sampled together may be compared during the statistical analysis. WYDOT will randomly compare three of their sublots to the three corresponding sublots of the contractors. A total of three pairs of VMA samples from WYDOT and the contractor will be compared.

Determine VMA using WYDOT 414VA.0. Report the VMA on Form T-414VA to the nearest 0.1.

Perform a two-tailed paired t-test on the density data as described in this section. Use the level of significance, α , of 0.02.

- Calculations: 1. Calculate the difference between the three WYDOT VMA samples and the three contractor VMA samples (ensure the VMA samples from the three selected equivalent sublots are used) using the following equation:

$$X_i - Y_i = Z_i$$

Where: i = individual sample
 X_i = WYDOT VMA y for sample p
 Y_i = contractor VMA for sample pair i
 Z_i = difference between paired samples for sample i

2. Determine the mean (average) of the differences using the following equation:

$$\bar{Z} = \left(\frac{1}{n}\right) \sum_{i=1}^n Z_i$$

Where: \bar{Z} = mean (average) sample VMA
 n = number of samples, three in this case
 \sum = sum of unit VMA

3. Calculate the sample standard deviation¹ of the differences in VMA samples. This is done using the sample standard deviation function on a calculator or spreadsheet according to the following equation:

$$s = \sqrt{\left(\frac{1}{n-1}\right) \sum_{i=1}^n (Z_i - \bar{Z})^2}$$

Where: s = sample standard deviation

- Paired t-test: 1. Select the appropriate value to use for s in calculating the t-test statistic:

If the sample standard deviation calculated in number 3 above is between 0.50 and 2.00, use the calculated standard deviation.

If the calculated standard deviation is less than 0.50, use $s = 0.50$.

If the calculated standard deviation is greater than 2.00, use $s = 2.00$.

¹ On most calculators and spreadsheets there are two standard deviations, a population standard deviation and a sample standard deviation: Use the sample standard deviation. To use a calculator, first determine and record the differences, Z_i . Then calculate the standard deviation of these differences.

- Calculate the t-test statistic using the following equation:

$$t = \frac{|\bar{Z}|}{\sqrt{\frac{s^2}{n}}}$$

Where: t = t-test statistic
 $|\bar{Z}|$ = absolute value of the mean differences in VMA for paired samples
s = standard deviation selected in number 1 of this section (t-tests)

- If t is less than the critical t value, $t_{crit} = 6.965$ (used for three pairs), then the t-test does not indicate a significant difference between the WYDOT, data, X_i , and the contractor's data, Y_i .

Example: The data on Table 1 of this section is used to perform the example calculations.

- Report the calculations on the WYDOT Form T-419.1VA.
- Record the three VMA samples for both, WYDOT, X_i , and the contractor, Y_i .
- Calculate the averages, Z_i .
- Calculate the standard deviation.

Table 1: Example Data: VMA

WYDOT, X_i	Contractor, Y_i	Difference, Z_i
14.0	13.0	1.0
15.5	14.0	1.5
14.6	12.5	2.1
Mean (average) (\bar{Z}) =		1.53
Standard Deviation (s) =		0.550

5. Calculate the value of s to determine the t-test statistic.

Since the standard deviation of 0.550 is between the minimum standard deviation of 0.5 and the maximum standard deviation of 2.00, use $s = 0.550$.

6. Calculate the t-test statistic (see number 2 of Paired t-test).

$$t = \frac{|\bar{Z}|}{\sqrt{\frac{s^2}{n}}} = \frac{|1.53|}{\sqrt{\frac{0.55^2}{3}}} = 4.818$$

Where: t = the t-test statistic.

7. The t-test statistic in the example is 4.818. The critical t value is 6.965 (see Note 2). Since the test statistic, 4.818, is less than the critical value, 6.965, conclude that the WYDOT data is not significantly different from the contractor's data. There is a 99 percent confidence level that the two data sets represent the same population statistically.

Further Evaluation:

1. If the average difference fails the T Critical Test, WYDOT's tests will be used and another correlation will be required. Follow Subsection 401.4.8 "*Verification*".
2. Resolve the discrepancy in accordance with Subsection 114.3.4, "*Resolving Field Test Discrepancies*".

Report: Report the results on Form T-419.1VA.

VERIFYING THE CONTRACTORS QUALITY CONTROL (QC) AIR VOIDS RESULTS

Scope: This statistical procedure compares the mix (hot plant mix, recycled hot plant mix, warm plant mix) Air Voids, determined by WYDOT with those determined by the contractor. A two-tailed paired t-test is run on the air voids determined by the two laboratories. This procedure determines whether one can be 99 percent confident that the two laboratories are achieving similar test results. This procedure will not detect minor differences between the two laboratories.

Use: This procedure determines whether densities determined by WYDOT and the contractor may be used interchangeably. If the data generated by WYDOT and the contractor are found to be significantly different, then the dispute resolution procedure will be followed.

The two-tailed paired t-test determines whether average air voids are significantly different.

If there is change in testing personnel or equipment, repeat the correlation using MTM 418.2VA process using production test results.

Reference

Documents: WYDOT 114 *WYDOT Standard Specifications*
WYDOT 401 *WYDOT Standard Specifications*
WYDOT 410VA *Sampling Plant Mix*
WYDOT 414VA.0 *Superpave Laboratory Mix Design and Field Mix
 Volumetric Acceptance*
WYDOT T-414VA *Volumetric Summary Results for VMA and VA*
WYDOT T-418.2VA *Comparisons of Volumetric Results*

Procedure: Collect one pair of samples from each subplot for all five sublots, for a total of five pairs of samples according to WYDOT 410VA. Per WYDOT 414VA assign each pair a label so that pairs sampled together may be compared during the statistical analysis. WYDOT will randomly compare 3 of their sublots to the 3 corresponding sublots of the contractors. A total of three pairs of Air Voids from WYDOT and the contractor will be compared.

Determine Air Voids using WYDOT 414VA.0. Report the Air Voids on Form T-414VA to the nearest 0.1%.

Perform a two-tailed paired t-test on the density data as described in this section. Use the level of significance, α , of 0.02.

- Calculations: 1. Calculate the difference between the three WYDOT Air Voids and the three contractor Air Voids (ensure the Air Voids from the three selected equivalent sublots are used) using the following equation:

$$X_i - Y_i = Z_i$$

Where: i = individual sample
 X_i = WYDOT Air Voids for sample p
 Y_i = contractor Air Voids for sample pair i
 Z_i = difference between paired samples for sample i

2. Determine the mean (average) of the differences using the following equation:

$$\bar{Z} = \left(\frac{1}{n}\right) \sum_{i=1}^n Z_i$$

Where: \bar{Z} = mean (average) sample Air Voids
 n = number of samples, three in this case
 \sum = sum of unit Air Voids

3. Calculate the sample standard deviation¹ of the differences in Air Voids. This is done using the sample standard deviation function on a calculator or spreadsheet according to the following equation:

$$s = \sqrt{\left(\frac{1}{n-1}\right) \sum_{i=1}^n (Z_i - \bar{Z})^2}$$

Where: s = sample standard deviation

- Paired t-test: 1. Select the appropriate value to use for s in calculating the t-test statistic:

If the sample standard deviation calculated in number 3 above is between 0.50 and 2.00, use the calculated standard deviation.

¹ On most calculators and spreadsheets there are two standard deviations, a population standard deviation and a sample standard deviation: Use the sample standard deviation. To use a calculator, first determine and record the differences, Z_i . Then calculate the standard deviation of these differences.

If the calculated standard deviation is less than 0.50, use $s = 0.50$.

If the calculated standard deviation is greater than 2.00, use $s = 2.00$.

- Calculate the t-test statistic using the following equation:

$$t = \frac{|\bar{Z}|}{\sqrt{\frac{s^2}{n}}}$$

Where: t = t-test statistic
 $|\bar{Z}|$ = absolute value of the mean differences in density for paired samples
 s = standard deviation selected in number 1 of this section (t-tests)

- If t is less than the critical t value, $t_{crit} = 6.965$ (used for three pairs), then the t-test does not indicate a significant difference between the WYDOT, data, X_i , and the contractor's data, Y_i .

Example: The data on Table 1 of this section is used to perform the example calculations.

- Report the calculations on the WYDOT Form T-419.2VA.
- Record the three air voids for both, WYDOT, X_i , and the contractor, Y_i .
- Calculate the averages, Z_i .
- Calculate the standard deviation.

Table 1: Example Data: Air Voids

WYDOT, X_i	Contractor, Y_i	Difference, Z_i
4.1	3.9	0.2
3.0	5.1	-2.1
3.9	4.7	-0.8

Mean (average) (\bar{Z}) = 0.9

Standard Deviation (s) = 1.15

5. Calculate the value of s to determine the t-test statistic.

Since the standard deviation of 1.15 is between the minimum standard deviation of 0.5 and the maximum standard deviation of 2.00, use $s = 1.15$.

6. Calculate the t-test statistic (see number 2 of Paired t-test).

$$t = \frac{|\bar{Z}|}{\sqrt{\frac{s^2}{n}}} = \frac{|0.9|}{\sqrt{\frac{1.15^2}{3}}} = 1.356$$

Where: t = the t-test statistic.

7. The t-test statistic in the example is 1.356. The critical t value is 6.965 (see Note 2). Since the test statistic, 1.356, is less than the critical value, 6.965, conclude that the WYDOT data is not significantly different from the contractor's data. There is a 99 percent confidence level that the two data sets represent the same population statistically.

Further Evaluation:

1. If the average difference fails the T Critical Test, WYDOT's tests will be used and another correlation will be required. Follow Subsection 401.4.8 "Verification".
2. Resolve the discrepancy in accordance with Subsection 114.3.4, "Resolving Field Test Discrepancies".

Report: Report the results on Form T-419.2VA.

VERIFYING THE CONTRACTORS QUALITY CONTROL (QC) CORE RESULTS

Scope: This statistical procedure compares the mix (hot plant mix, recycled hot plant mix, warm plant mix) core densities, determined by WYDOT with those determined by the contractor. A two-tailed paired t-test is run on the core densities determined by the two laboratories. This procedure determines whether one can be 99 percent confident that the two laboratories are achieving similar test results. This procedure will not detect minor differences between the two laboratories.

Use: This procedure determines whether densities determined by WYDOT and the contractor may be used interchangeably. If the data generated by WYDOT and the contractor are found to be significantly different, then the dispute resolution procedure will be followed.

The two-tailed paired t-test determines whether average core densities are significantly different. The directional bias test indicates if one laboratory is getting consistently higher or lower results than the other.

If there is change in testing personnel or equipment, repeat the correlation using MTM 418.3VA process using production test results.

Reference

Documents: WYDOT 114 *WYDOT Standard Specifications*
WYDOT 401 *WYDOT Standard Specifications*
WYDOT 417VA.0 *Density Testing for Compacted Mix*
WYDOT T-417VA *In Place Pavement Density Report*
WYDOT T-419.3VA *Verifying Volumetric Core Results*

Procedure: Collect three pairs of cores from each subplot for all five sublots, for a total of fifteen pairs of cores according to WYDOT 417VA. Per WYDOT 417VA assign each pair a label so that pairs sampled together may be compared during the statistical analysis. WYDOT will randomly compare 3 of their sublots to the 3 corresponding sublots of the contractors. At total of nine pairs of cores from WYDOT and the contractor will be compared.

Determine the density of each core using WYDOT 417VA.0. Calculate and report the Percent Max Density on Form T-417VA to the nearest 0.1 lb/ft³.

Perform a two-tailed paired t-test on the density data as described in this section. Use the level of significance, α , of 0.02.

If any directional bias occurs, or if the t-test indicates that the two laboratories are achieving significantly different results, perform further evaluation of the correlation between the laboratories. “Directional bias” is considered to exist when all, or all but one, of the tests are higher for one laboratory than the other. “Directional bias” does not exist when at least two of the tests are less than, or equal to the corresponding paired test.

- Calculations: 1. Calculate the difference between the Nine WYDOT densities and the Nine contractor densities (ensure the cores from the three selected equivalent sublots are used) using the following equation:

$$X_i - Y_i = Z_i$$

Where: i = individual sample
 X_i = WYDOT core density for sample p
 Y_i = contractor core density for sample pair i
 Z_i = difference between paired samples for sample i

2. Determine the mean (average) of the differences using the following equation:

$$\bar{Z} = \left(\frac{1}{n}\right) \sum_{i=1}^n Z_i$$

Where: \bar{Z} = mean (average) sample core density
 n = number of samples, nine in this case
 \sum = sum of unit densities

3. Calculate the sample standard deviation¹ of the differences in core densities. This is done using the sample standard deviation function on a calculator or spreadsheet according to the following equation:

$$s = \sqrt{\left(\frac{1}{n-1}\right) \sum_{i=1}^n (Z_i - \bar{Z})^2}$$

Where: s = sample standard deviation

¹ On most calculators and spreadsheets there are two standard deviations, a population standard deviation and a sample standard deviation: Use the sample standard deviation. To use a calculator, first determine and record the differences, Z_i . Then calculate the standard deviation of these differences.

Paired t-test: 1. Select the appropriate value to use for s in calculating the t-test statistic:

If the sample standard deviation calculated in number 3 above is between 0.50 and 2.00, use the calculated standard deviation.

If the calculated standard deviation is less than 0.50, use $s = 0.50$.

If the calculated standard deviation is greater than 2.00, use $s = 2.00$.

2. Calculate the t-test statistic using the following equation:

$$t = \frac{|\bar{Z}|}{\sqrt{\frac{s^2}{n}}}$$

Where: t = t-test statistic
 $|\bar{Z}|$ = absolute value of the mean differences in density for paired samples
 s = standard deviation selected in number 1 of this section (t-tests)

3. If t is less than the critical t value², $t_{crit} = 2.896$ (used for nine pairs), then the t-test does not indicate a significant difference between the WYDOT, data, X_i , and the contractor=s data, Y_i .

4. Evaluate for directional bias. “Directional bias” is considered to exist when all, or all but one, of the tests are higher for one laboratory than the other. “Directional bias” does not exist when at least two of the tests are less than, or equal to the corresponding paired test. If all but one of the densities determined by one laboratory is larger than the paired densities of the other laboratory, directional bias is present. To verify directional bias see “Further Evaluation” at the end of this section.

Example: The data on Table 1 of this section is used to perform the example calculations.

1. Report the calculations on the WYDOT Form T-419.3VA.
2. Record the nine unit weights for both, WYDOT, X_i , and the contractor, Y_i .
2. Calculate the averages, Z_i .
3. Calculate the standard deviation.

Table 1: Example Data: Core Densities, lb/ft³

WYDOT, X_i	Contractor, Y_i	Difference, Z_i
141.4	140.9	0.5
142.3	141.7	0.6
140.7	140.8	-0.1
141.6	141.4	0.2
142.1	141.6	0.5
141.0	140.4	0.6
142.0	142.4	-0.4
142.4	141.9	0.5
140.5	140.4	0.1

$$\text{Mean (average) } (\bar{Z}) = 0.28$$

$$\text{Standard Deviation (s)} = 0.350$$

5. Calculate the value of s to determine the t-test statistic.

Since the standard deviation of 0.35 is less than the minimum standard deviation of 0.50, use $s = 0.50$.

6. Calculate the t-test statistic (see number 2 of Paired t-test).

$$t = \frac{|\bar{Z}|}{\frac{s}{\sqrt{n}}} = \frac{|0.28|}{\frac{0.50}{\sqrt{9}}} = 1.68$$

Where: t = the t-test statistic.

7. The t-test statistic in the example is 1.68. The critical t value is 2.896 (see Note 2). Since the test statistic, 1.68, is less than the critical value, 2.896, conclude that the WYDOT data is not significantly different from the

contractor's data. There is a 99 percent confidence level that the two data sets represent the same population statistically.

8. There is no directional bias since seven of the nine sample pairs had higher densities with the WYDOT data than with the contractor data.

Since there is no directional bias, further evaluation is not needed to find the cause of the directional bias.

Further Evaluation:

1. If the average difference fails the T Critical Test, WYDOT's tests will be used and another correlation will be required. Follow Subsection 401.4.8 "*Verification*".
2. Resolve the discrepancy in accordance with Subsection 114.3.4, "*Resolving Field Test Discrepancies*".
3. For Informational Purposes Only:

WYDOT and Contractors swap cores and observe QC testing.

Report: Report the results on Form T-419.3VA.