ARIZONA DEPARTMENT OF TRANSPORTATION * MATERIALS GROUP

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CHANGE LETTER

MATERIALS TESTING MANUAL	CHANGE LETTER NO. 29
SUBJECT: Title Page; Table of Contents; Series 800 Cover Sheet; Arizona Test Methods 815d, 832a, and 833.	EFFECTIVE DATE: February 22, 2013

SUMMARY:

NOTE: Unless otherwise specified, changes issued under this Change Letter are effective for projects with a bid opening date on or after February 22, 2013. Retain items removed from the Materials Testing Manual under this change letter for use as necessary on projects with a bid opening date prior to February 22, 2013.

1. TITLE PAGE - The Title Page has been revised to show the latest Change Letter number and revision date. Please replace the existing Title Page with the attached.

2. TABLE OF CONTENTS - The Table of Contents has been revised to reflect the changes made in this Change Letter. Please replace the existing Table of Contents with the attached.

3. Series 800 Cover Sheet - "DESIGN"

   Series 800 Cover Sheet has been revised to reflect the changes made in this Change Letter. Please replace the existing Series 800 Cover Sheet with the attached.

4. The following two test methods have been revised in their entirety, including the use of the newly adopted format for Arizona Test Methods. Please replace the existing test methods with the attached.

   Arizona Test Method 815d – "MARSHALL MIX DESIGN METHOD FOR ASPHALTIC CONCRETE".

   Arizona Test Method 832a – "MARSHALL MIX DESIGN METHOD FOR ASPHALTIC CONCRETE (ASPHALT-RUBBER) [AR-AC]".

5. The following new test method has been added to the Materials Testing Manual.

   Arizona Test Method 833 – "MARSHALL MIX DESIGN METHOD FOR ASPHALTIC CONCRETE WITH RECLAIMED ASPHALT PAVEMENT (RAP)"

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Assistant State Engineer
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Attachments

MATERIALS

TESTING MANUAL

SAMPLING AND TESTING PROCEDURES

PREPARED BY:
ARIZONA DEPARTMENT OF TRANSPORTATION
INTERMODAL TRANSPORTATION DIVISION
MATERIALS GROUP

REVISED TO CHANGE LETTER NO. 29
(February 22, 2013)

MATERIALS TESTING MANUAL

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**** The above Arizona Test Methods, and also commonly used AASHTO procedures in this category, are shown on Series 100 Cover Sheet (December 15, 2010).

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****** The above Arizona Test Methods, and also commonly used AASHTO and ASTM procedures in this category are show on Series 300 Cover Sheet (March 31, 2010).

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****** The above Arizona Test Methods, and also commonly used AASHTO procedures in this category, are show on Series 400 Cover Sheet (September 28, 2012).

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****** The above Arizona Test Methods, and also commonly used AASHTO and ASTM procedures and specifications are shown on Series 500 Cover Sheet (July 15, 2005).

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****** Commonly used AASHTO and ASTM procedures in this category are show on Series 600 Cover Sheet (July 15, 2005).

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****** The above Arizona Test Methods are also shown on Series 800 Cover Sheet (February 22, 2013).

SERIES 900 MATERIALS QUALITY ASSURANCE PROGRAM
(January 7, 2011)

Appendix A - BLANK
Appendix B - BLANK
Appendix C - Sampling Guide Schedule

SERIES 1000 CERTIFICATES (July 15, 2005)

APPENDIX

APPENDIX A1 Rounding Procedure (July 15, 2005)
APPENDIX A2 Metric Guide (July 15, 2005)
APPENDIX A3 Equipment Calibration and Verification (September 28, 2012)

SERIES 800

DESIGN

The following methods shall be performed in accordance with the respective designation:

ARIZONA TEST METHODS:

TITLE	DESIGNATION
Evaluation of Profiles ……..……………………..…………………	ARIZ 801a
Effect of Water on Strength of Compacted Bituminous Mixtures (Immersion Compression Test) ……..……………….	ARIZ 802g
Centrifuge Kerosene Equivalent of Aggregate, Including K-Factor …………………………………………..……..	ARIZ 805b
Maximum Theoretical Specific Gravity of Laboratory Prepared Bituminous Mixtures (Rice Test) ……..…..….……	ARIZ 806e
Design of Slurry Seal ………………..………………………….….	ARIZ 807
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Evaluation of Pavement Smoothness …………..…..……………..	ARIZ 829a
Marshall Mix Design Method for Asphaltic Concrete (Asphalt-Rubber) [AR-AC] ……………………..………………	ARIZ 832a
Marshall Mix Design Method for Asphaltic Concrete with Reclaimed Asphalt Pavement (RAP) ………………….………	ARIZ 833

NOTE: It shall be assured that the appropriate methods as given in the project requirements are being adhered to.

ADOT
Intermodal Transportation

ARIZ 815d
February 22, 2013
(27 Pages)

MARSHALL MIX DESIGN METHOD FOR ASPHALTIC CONCRETE

(An Arizona Method)

1. SCOPE

1.1 This method is used to design Asphaltic Concrete mixes using 4-inch diameter Marshall apparatus.

1.2 This test method involves hazardous material, operations, and equipment. This test method does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1.3 See Appendix A1 of the Materials Testing Manual for information regarding the procedure to be used for rounding numbers to the required degree of accuracy.

1.4 A listing of subsequent Sections and Figures in this procedure is given below:

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2. TEST METHODS AND APPARATUS

2.1 This test method is used in conjunction with the test methods listed below. Requirements for the frequency of equipment calibration and verification are found in Appendix A3 of the Materials Testing Manual. The required apparatus is shown in the individual test methods, as appropriate.

2.2 Arizona Test Methods:

- ARIZ 201 Sieving of Coarse and Fine Graded Soils and Aggregates
- ARIZ 205 Composite Grading
- ARIZ 210 Specific Gravity and Absorption of Coarse Aggregate
- ARIZ 211 Specific Gravity and Absorption of Fine Aggregate
- ARIZ 212 Percentage of Fractured Coarse Aggregate Particles
- ARIZ 238 Percent Carbonates in Aggregate
- ARIZ 247 Particle Shape and Texture of Fine Aggregate Using Uncompacted Void Content
- ARIZ 248 Alternate Procedures for Sieving of Coarse and Fine Graded Soils and Aggregates
- ARIZ 251 Combined Coarse and Fine Aggregate Specific Gravity and Absorption
- ARIZ 410 Compaction and Testing of Bituminous Mixtures Utilizing Four Inch Marshall Apparatus
- ARIZ 415 Bulk Specific Gravity and Bulk Density of Compacted Bituminous Mixtures
- ARIZ 416 Preparing and Splitting Field Samples of Bituminous Mixtures for Testing
- ARIZ 802 Effect of Water on Strength of Compacted Treated and Untreated Bituminous Mixtures (Immersion Compression Test)
- ARIZ 806 Maximum Theoretical Specific Gravity of Laboratory Prepared Bituminous Mixtures (Rice Test)

2.1.2 AASHTO Test Methods:

- AASHTO T 96 Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
- AASHTO T 176 Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
- AASHTO T 228 Specific Gravity of Semi-Solid Bituminous Materials

Note 1: Testing by AASHTO T 228 shall be performed at 77 °F.

- AASHTO T 316 — Viscosity Determination of Asphalt Binder Using Rotational Viscometer

2.1.3 ASTM Standard:

- ASTM D 2493 — Standard Viscosity-Temperature Chart for Asphalts

3. MATERIALS

3.1 Mineral Aggregate - The mineral aggregate used in the design shall be produced material from the source(s) for the project.

3.1.1 The composited gradation of the aggregate without admixture, and the composited gradation of the aggregate-mineral admixture blend shall comply with the grading limits of the specifications.

3.1.2 The composited mineral aggregate shall conform to the requirements of the specifications for Sand Equivalent (AASHTO T 176), Combined Bulk Oven Dry Specific Gravity (ARIZ 251), Combined Water Absorption (ARIZ 251), Fractured Coarse Aggregate Particles (ARIZ 212), Uncompacted Void Content (ARIZ 247), and Percent Carbonates (ARIZ 238) when applicable.

3.1.3 Mineral aggregate from each source shall be tested separately for compliance to the project requirements for Abrasion (AASHTO T 96).

3.2 Bituminous Material - The bituminous material used in the design shall be an asphalt binder, conforming to the requirements of Section 1005 of the specifications, which is to be used in the production of the asphaltic concrete. The specific gravity of the asphalt binder shall be determined in accordance with AASHTO T 228 (at 77 °F).

3.3 Mineral Admixture - Mineral admixture is required. The mineral admixture used in the design shall be the same type of material to be used in production of the asphaltic concrete. The mineral admixture shall conform to the requirements of the specifications.

3.4 Batch Plants - Mix designs developed for asphaltic concrete which is to be produced in a batch plant shall be prepared in accordance with this procedure, modified as follows:

3.4.1 Aggregate samples will be obtained from the hot bins for all testing except Sand Equivalent. Testing for Sand Equivalent will be performed on aggregate stockpile samples proportioned and composited to meet the mix design composite without admixture. Any method may be used to combine the aggregate stockpile samples for Sand Equivalent testing as long as the resultant gradation is representative of the mix design composite gradation without admixture.

3.4.2 The mix design shall provide component percentages and composite gradations for both stockpile and hot bin materials.

4. DETERMINATION OF COMPOSITE GRADATION

4.1 The gradation of the aggregate from each individual component stockpile or bin shall be determined in accordance with ARIZ 248 using washed sieve analysis Alternate #3, Alternate #4, or Alternate #5. For Alternate #5, washing of the coarse aggregate may be performed on the composite Plus No. 4 material and applied to the composite percent pass the minus No. 200 determined from the unwashed coarse sieving and washed fine sieving of the individual stockpiles.

4.2 The composite gradation of the mineral aggregate is determined using desired percentages of each component based on washed sieve analysis. Mix designs may be developed based on bin or stockpile material, as appropriate for the respective mix production facility to be used.

4.3 The mineral aggregate composite shall be determined in accordance with ARIZ 205, paragraph 2(e).

4.4 The aggregate-mineral admixture blend composite is determined by adjusting the mineral aggregate composite (percent passing) for mineral admixture by performing the calculation in Equation 1 for each sieve:

Equation 1:

$$\begin{pmatrix}\text{\% passing} \\ \text{each sieve} \\ \text{[Adjusted for} \\ \text{Mineral} \\ \text{Admixture]}\end{pmatrix} = \frac{\begin{pmatrix}\text{\% passing} \\ \text{each sieve in} \\ \text{the aggregate} \\ \text{composite}\end{pmatrix} + \begin{pmatrix}\text{\% Mineral} \\ \text{Admixture}\end{pmatrix}}{(100) + (\text{\% Mineral Admixture})} \times 100$$

4.5 The composited gradation of the aggregate and the composited gradation of the aggregate-mineral admixture blend shall be shown on the design report, along with the percentage of each material.

5. PREPARING AGGREGATE/MINERAL ADMIXTURE SAMPLES FOR MIX DESIGN TESTING

5.1 Based on the stockpile or bin composite aggregate gradation, the aggregate samples needed for mix design tests are prepared as follows.

5.1.1 Dry the mineral aggregate from each individual stockpile at a temperature not exceeding any temperature restrictions specified in subsequent test procedures. Drying shall be performed until no further weight loss is obtained from continued drying.

5.1.2 Representative samples of aggregate material which is retained on the individual No. 8 and larger sieve sizes and the minus No. 8 material from each stockpile or bin are used to prepare the samples for mix design testing.

5.1.3 Table 1 shows the aggregate sample sizes, the number of samples required for each test listed, and which samples include mineral admixture. The aggregate weight shown for Maximum Theoretical Specific Gravity will provide three Rice test specimens. the amount shown for Density-Stability/Flow will produce three Marshall specimens, and the amount shown for Immersion Compression (IMC) will produce two specimens. Example weigh-up sheets are shown in Figures 2 and 3.

Table 1

Sample Type	Sample Size	Number of Samples
Fractured Coarse Aggregate Particles (ARIZ 212)	Required grams of Mineral Aggregate as determined by test method [No mineral admixture]	1
Percent Carbonates (ARIZ 238) (When required)	300 grams of Mineral Aggregate [No mineral admixture]	1
Abrasion (AASHTO T 96)	5000 grams of Mineral Aggregate as per test method for grading type [No mineral admixture]	1
Fine Aggregate Specific Gravity/ Absorption (ARIZ 211)	1200 grams of Mineral Aggregate [No mineral admixture]	1
Coarse Aggregate Specific Gravity/Absorption (ARIZ 210)	Required grams of Mineral Aggregate as determined by the Nominal Maximum Aggregate Size [No mineral admixture]	1

Table 1 (Continued)		
Sand Equivalent (AASHTO T 176)	500 to 750 grams of Mineral Aggregate [No mineral admixture]	1
Uncompacted Void Content (ARIZ 247)	Minimum 500 grams of Mineral Aggregate [No mineral admixture]	1
Minus No. 8 Make-Up Material	An adequate amount (normally 500 grams) of Mineral Aggregate [No mineral admixture]	1
Marshall Density-Stability/Flow (ARIZ 415 and ARIZ 410, as modified in Sections 9 and 10 respectively)	3300 grams of Mineral Aggregate (See Note 2) [Plus mineral admixture, by percent required by ARIZ 802 (as modified in Section 13)]	3 (See Note 3) [Each sample yields 1 set of 3 Marshall Specimens]
Maximum Theoretical Specific Gravity (Rice Test) (ARIZ 806, as modified in Section 11)	3000 grams of Mineral Aggregate [Plus mineral admixture, by percent required by ARIZ 802 (as modified in Section 13)]	1 [Yields 3 test specimens]
Immersion Compression (IMC) (ARIZ 802, as modified in Section 13)	3400 grams of Mineral Aggregate (See Note 2) [Plus required percent of mineral admixture]	3 [Each sample yields 1 set of 2 IMC Specimens]

Note 2: Generally the weight of mineral aggregate will provide specimens of acceptable heights, but adjustments may be necessary in some cases. Use Equation 2 to adjust the weight of aggregate as necessary to conform to specimen height requirements of 2.500 $\pm$ 0.200 inches for Marshall Density-Stability/Flow specimens and 4.000 $\pm$ 0.100 inches for IMC specimens.

***Equation 2*:**

$$\begin{bmatrix}\text{Adjusted Weight} \\ \text{of Aggregate}\end{bmatrix} = \frac{\begin{pmatrix}\text{Combined Bulk O.D.} \\ \text{Agg. Specific Gravity}\end{pmatrix}}{2.650} \times \begin{pmatrix}\text{3300 grams (for Marshall} \\ \text{Density - Stability/Flow)} \\ \text{or 3400 grams (for} \\ \text{Immersion Compression)}\end{pmatrix}$$

Note 3: Requires one sample for each asphalt binder content to be tested (minimum of 3 asphalt binder contents, with 3 Marshall specimens at each asphalt binder content).

5.1.4 After the aggregate samples for the Marshall, Rice, and IMC specimens have been composited, add the required amount of mineral admixture, by dry weight of the aggregate, and mix thoroughly. Add 3% water, by dry weight of the aggregate, to each sample and mix thoroughly to wet the mineral admixture and aggregate surfaces.

5.1.5 Testing utilizing the prepared virgin aggregate-mineral admixture samples for Marshall, Rice, and IMC will be performed as specified in Sections 8-10, 11, and 13, respectively.

6. AGGREGATE SPECIFIC GRAVITIES AND ABSORPTION

6.1 Determine the Bulk Oven Dry, S.S.D., Apparent Specific Gravities and Absorption for the fine aggregate (minus No. 4) and the coarse aggregate (plus No. 4) in accordance with ARIZ 211 and ARIZ 210, respectively.

6.2 Determine the combined bulk oven dry specific gravity of the fine aggregate and the coarse aggregate without mineral admixture and also the combined water absorption of the fine aggregate and the coarse aggregate without mineral admixture, in accordance with ARIZ 251.

6.2.1 The combined aggregate bulk oven dry specific gravity without mineral admixture and the combined aggregate water absorption without mineral admixture are used only to determine compliance with specification requirements.

6.3 Using Equation 3, calculate the Combined Bulk Oven Dry (Gsb), S.S.D., and Apparent Specific Gravities of the aggregate-mineral admixture blend.

Equation 3:

$$\begin{pmatrix}\text{Combined Specific Gravity}\\ \text{of Aggregate and Mineral}\\ \text{Admixture Blend}\end{pmatrix} = \frac{P_f + P_c + P_{admix}}{\frac{P_f}{G_f} + \frac{P_c}{G_c} + \frac{P_{admix}}{G_{admix}}}$$

Where:

P_f, P_c = Weight percent of fine aggregate (minus No. 4) and coarse aggregate (plus No. 4) respectively. Determined from the aggregate composite without mineral admixture.

P_{admix} = Percent mineral admixture by weight of the aggregate.

$P_f + P_c$ = 100

$P_f + P_c + P_{admix}$ = 100 + % Mineral Admixture

G_f, G_c = Bulk Oven Dry, S,S.D., or Apparent specific gravity of the fine aggregate and the coarse aggregate respectively.

G_{admix} = Specific gravity of the mineral admixture.
Type I or II Cement = 3.14
Type IP Cement = 3.00
Hydrated Lime = 2.20

Example [for combined Bulk Oven Dry Specific Gravity (G_{sb})]:

P_f = 59
P_c = 41
G_f = 2.593
G_c = 2.634
G_{admix} = 3.14 (Type II Cement)
P_{admix} = 1.0

$$\left[\begin{array}{l}\text{Example of Combined} \\ \text{Bulk Oven Dry Specific} \\ \text{Gravity } (G_{sb}) \text{ of Aggregate} \\ \text{and Mineral Admixture}\end{array}\right] = \frac{59 + 41 + 1.0}{\frac{59}{2.593} + \frac{41}{2.634} + \frac{1.0}{3.14}} = 2.614$$

6.4 Using Equation 4, calculate the Combined Water Absorption of the aggregate-mineral admixture blend.

Equation 4:

$$\left(\begin{array}{l}\text{Combined Water Absorption} \\ \text{of Aggregate and Mineral} \\ \text{Admixture Blend}\end{array}\right) = \frac{(P_f \text{ x } A_f) + (P_c \text{ x } A_c) + (P_{admix} \text{ x } A_{admix})}{P_f + P_c + P_{admix}}$$

Where: P_f, P_c = Weight percent of fine aggregate (minus No. 4) and coarse aggregate (plus No. 4) respectively. Determined from the aggregate composite without mineral admixture.

P_{admix} = Percent mineral admixture by weight of the aggregate.

$P_f + P_c$ = 100

$P_f + P_c + P_{admix}$ = 100 + % Mineral Admixture

A_f, A_c = Percent water absorption of the coarse aggregate and the fine aggregate respectively.

A_{admix} = Percent water absorption of mineral admixture (assumed to be 0.0%).

Example:

$$P_f = 59$$
$$P_c = 41$$
$$A_f = 1.28$$
$$A_c = 0.79$$
$$P_{admix} = 1.0$$
$$A_{admix} = 0.00$$

$$\begin{bmatrix} \text{Combined Water} \\ \text{Absorption of} \\ \text{Aggregate and} \\ \text{Mineral Admixture} \end{bmatrix} = \frac{(59 \times 1.28) + (41 \times 0.79) + (1.0 \times 0.00)}{59 + 41 + 1.0} = 1.07$$

7. LABORATORY MIXING AND COMPACTION TEMPERATURES

7.1 The rotational viscosity of the asphalt binder at 275 °F and 350 °F shall be determined in accordance with AASHTO T 316, and a viscosity - temperature curve developed in accordance with ASTM D 2493.

7.2 The laboratory mixing temperature range is defined as the range of temperatures where the un-aged asphalt binder has a rotational viscosity of 0.17 ± 0.02 Pascal·seconds. The actual laboratory mixing temperature used is normally selected at or near the mid-point of the range.

7.3 The laboratory compaction temperature range is defined as the range of temperatures where the un-aged asphalt binder has a rotational viscosity of 0.28 ± 0.03 Pascal·seconds. The actual laboratory compaction temperature used is normally selected at or near the mid-point of the range.

7.4 The viscosity - temperature curve shall be included in the mix design report. For PG asphalt binders that have a maximum laboratory mixing temperature exceeding 325 °F or a maximum laboratory compaction temperature exceeding 300 °F, the laboratory mixing and compaction temperature ranges shall be specified in writing by the asphalt binder supplier. A viscosity-temperature curve will meet this requirement for written documentation if the viscosity-temperature curve is developed and submitted by the binder supplier and includes language that the recommended laboratory mixing and compaction temperatures are within acceptable ranges, and shall include a statement indicating the maximum laboratory mixing temperature to which the binder can be heated without damage. The laboratory mixing and compaction temperature ranges, as well as the actual laboratory mixing and compaction temperatures used, shall be reported on the mix design.

8. PREPARATION OF SPECIMENS FOR BULK SPECIFIC GRAVITY/BULK DENSITY AND MARSHALL STABILITY/FLOW DETERMINATION

8.1 Specimens shall be prepared as described herein, utilizing the apparatus specified in ARIZ 410.

Note 4: Normally a range of 3 different asphalt binder contents at 0.5% increments will provide sufficient information, although in some cases it may be necessary to prepare additional sets of samples at other asphalt binder contents.

8.2 The aggregate-mineral admixture samples, prepared as specified in Section 5, shall be dried to constant weight at the laboratory mixing temperature ± 5 ºF and shall be at this temperature at the time of mixing with the asphalt binder. If necessary, a small amount of proportioned minus No. 8 aggregate make-up material shall be added to bring samples to the desired weight.

8.3 Before each batch of asphaltic concrete is mixed, the asphalt binder shall be heated in a loosely covered container in a forced draft oven for approximately 2 hours or as necessary to bring the asphalt binder to the laboratory mixing temperature ± 5 ºF.

8.4 Using Equation 5, calculate the weight of asphalt binder to be used for each asphalt binder content:

Equation 5:

$$\begin{bmatrix}\text{Weight of}\\\text{Asphalt Binder}\end{bmatrix} = \frac{\begin{bmatrix}\text{Weight of Aggregate}\\\text{and Mineral Admixture}\end{bmatrix}}{100 - \begin{bmatrix}\text{Percent of}\\\text{Asphalt Binder}\end{bmatrix}} \times \begin{bmatrix}\text{Percent of}\\\text{Asphalt Binder}\end{bmatrix}$$

Example (for Marshall specimens with 4.5% Asphalt Binder) (See Note 4):

$$\begin{bmatrix}\text{Weight of}\\\text{Asphalt Binder}\end{bmatrix} = \frac{3333}{100 - 4.5} \times 4.5 = 157.1 \text{ grams}$$

Note 5: Before each batch is mixed, the mixing bowl and whip shall be heated to the laboratory mixing temperature ± 5 ºF.

8.5 The aggregate-mineral admixture blend and the appropriate amount of asphalt binder shall be mixed together for 90 to 120 seconds at the required laboratory mixing temperature ± 5 ºF. **Mechanical mixing is required.**

Note 6: Although a wide range of mixers may provide the desired well-coated homogeneous mixture, commercial dough mixers with whips are often used. Minimum recommended capacity of the mixing bowl is 12 quarts.

Note 7: After mechanical mixing, hand mixing shall be used as necessary to produce a well-coated homogeneous mixture.

8.6 Immediately after mixing, each batch of asphaltic concrete shall be thoroughly blended and spread according to the procedures described in ARIZ 416. The circular mass shall be cut into 6 equal pie-shaped segments. Take opposite segments for each individual specimen and use up the entire batch.

8.7 Each individual specimen shall be spread in a large pan at nominal single-stone thickness. Avoid stacking particles as feasible. The specimens shall be oven-cured for 2 hours ± 10 minutes at the laboratory compaction temperature ± 5 ºF.

8.8 A mold assembly (base plate, mold, and collar) shall be heated to the laboratory compaction temperature ± 5 ºF. The face of the compaction hammer shall be thoroughly cleaned and heated on a hot plate set at the laboratory compaction temperature ± 5 ºF. A suitable shield, baffle plate, or sand bath shall be used on the surface of the hot plate to minimize localized overheating of the face of the hammer.

8.9 Place a 4-inch diameter paper disc in the bottom of the mold before the mixture is introduced. Quickly place the mixuture into the mold using a transfer bowl or other suitable device. Spade the mixture vigorously with a heated flat metal spatula, with a blade approximately 1-inch wide and 6-inches long and stiff enough to penetrate the entire layer of material, 15 times around the perimeter and 10 times at random into the mixture, penetrating the mixture to the bottom of the mold. Smooth the surface of mix to a slightly rounded shape.

8.10 Before compaction, put the mold containing the mixture in an oven as necessary to heat the mixture to the required laboratory compaction temperature ± 5 ºF. The specimen shall not be heated for more than one hour after being placed in the mold. Prior to compaction, it shall be verified that the mixture is at the required temperature. An electronic temperature probe with a digital display or a long-stem metal thermometer with a dial face shall be used. The use of an infrared temperature gun is not allowed.

8.11 Immediately upon removing the mold assembly loaded with mix from the oven, place a paper disc on top of mixture, place the mold assembly on the compaction pedestal in the mold holder, and apply 75 blows with the compaction hammer. Remove the base plate and collar, and reverse and reassemble the mold. Apply 75 compaction blows to the face of the reversed specimen.

Note 8: The compaction hammer shall apply only one blow after each fall, that is, there shall not be a rebound impact. The compaction hammer shall meet the requirements specified in Subsection 2.4 of ARIZ 410.

8.12 Remove the collar and top paper disc. Remove the base plate and remove the bottom paper disc while the specimen is still hot.

Note 9: Paper discs need to be removed while the specimen is hot. The discs are difficult to remove after the specimens have cooled.

8.13 Allow each compacted specimen to cool until they are cool enough to be extruded without damaging the specimen.

Note 10: Generally specimens can be extruded without damage when they are at a temperature of approximately 77 to 90 ºF.

Note 11: Cooling may be accomplished at room temperature, or in a 77 ºF air bath. If more rapid cooling is desired, the mold and specimen may be placed in front of a fan until cool.

8.14 Extrude the specimen by orienting the mold so that the ram pushes on the bottom face (base plate face) of the specimen. If any specimen is deformed or damaged during extrusion, the entire set of specimens at that asphalt binder content shall be discarded and a new set prepared.

8.15 Immediately upon extrusion, measure and record the height of the specimen to the nearest 0.001 inch and determine and record its weight in air to the nearest 0.1 gram. Compacted specimens shall be 2.500 ± 0.200 inches in height. If this criteria is not met for the specimens at each asphalt binder content, the entire set of specimens at that asphalt binder content shall be discarded and a new set prepared after necessary adjustments in the weight of aggregate have been made using Equation 2 (see Note 2 in Table 1).

8.16 Repeat the procedures in Subsections 8.4 through 8.15 for the required specimens.

9. BULK SPECIFIC GRAVITY/BULK DENSITY OF SPECIMENS

9.1 Determine the bulk specific gravity and bulk density of the three compacted specimens at each asphalt binder content in accordance with Method A of ARIZ 415. The determination of the “Weight in Water” and “S.S.D. Weight" of each specimen will be completed before the next specimen is submerged for its "Weight in Water" determination.

Note 12: Specimens fabricated in the laboratory that have not been exposed to moisture do not require drying after extrusion from the molds. The specimen weight in air obtained in Subsection 9.1 is its dry weight.

9.2 For each asphalt binder content, the densities of individual compacted specimens shall not differ by more than 2.0 pcf. If this density requirement is not met, the entire set of specimens at that asphalt binder content shall be discarded and a new set of specimens prepared.

9.3 For each set of three specimens, determine the average bulk specific gravity (G_{mb}), and using that value calculate the average bulk density (G_{mb} multiplied by 62.3 lb./cu. ft.).

10. MARSHALL STABILITY AND FLOW DETERMINATION

10.1 Specimens shall be tested for Marshall Stability and Flow utilizing the apparatus specified in ARIZ 410.

10.2 For each specimen, determine the uncorrected stability, the stability (corrected for height), and the flow according to ARIZ 410, Subsections 4.6 through 4.11. In addition, determine the average stability (corrected for height) and average flow for each set of specimens prepared at each asphalt binder content.

11. MAXIMUM THEORETICAL SPECIFIC GRAVITY (RICE TEST)

11.1 The maximum theoretical specific gravity of the mixture shall be determined in accordance with ARIZ 806 with the following modifications:

11.1.1 Prepare the specimens including mineral admixture according to the procedures described in Section 5 and Subsections 8.2 through 8.5 using 5.5% or 6.0% asphalt binder by total mix weight. A liquid anti-stripping agent is not used.

11.1.2 Immediately after mixing, the material shall be thoroughly blended and spread according to the procedures described in ARIZ 416. The circular mass shall be cut into 6 equal pie-shaped segments. Take opposite segments for each individual test sample and use up the entire batch.

11.1.3 Each individual test sample shall be spread in a large pan at nominal single-stone thickness. Avoid stacking particles as feasible. The test samples shall be oven-cured for 2 hours ± 10 minutes at the laboratory compaction temperature ± 5 °F.

11.1.4 After curing, each test sample shall be spread on a sheet of heavy paper or in a large flat bottom pan. Before the samples are completely cooled, separate the particles of the mixture, taking care not to fracture the mineral aggregate particles, so that the particles of the fine aggregate portion are not larger than ¼ inch. Allow the test samples to cool to room temperature.

11.1.5 Using Equation 6, calculate the effective specific gravity of the combined aggregate and mineral admixture (G_{se}).

Equation 6:

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

Where:

G_{se} = Effective specific gravity of the combined aggregate and mineral admixture.

P_b = Asphalt binder content at which the Rice test was performed (Rice P_b).

G_{mm} = Measured maximum theoretical specific gravity of the mix at Rice P_b.

G_b = Specific gravity of the asphalt binder.

Example: $P_b = 5.5$
$G_{mm} = 2.436$
$G_b = 1.032$

$$G_{se} = \frac{100 - 5.5}{\frac{100}{2.436} - \frac{5.5}{1.032}} = 2.645$$

11.1.6 Using Equation 7, calculate the maximum theoretical specific gravity (G_{mm}) for each asphalt binder content.

Note 13: G_{se} is considered constant regardless of the asphalt binder content.

Equation 7:

$$G_{mm} = \frac{100}{\frac{P_{sa}}{G_{se}} + \frac{P_b}{G_b}}$$

Where:
G_{mm} = Calculated maximum theoretical specific gravity of the mix at each asphalt binder content P_b.
P_{sa} = Aggregate and mineral admixture content, percent by total weight of mix (100-P_b).
P_b = Percent asphalt binder content, by total weight of mix, for each asphalt binder content.
G_{se} = Effective specific gravity of the combined aggregate and mineral admixture.
G_b = Specific gravity of the asphalt binder.

Example (for 4.5% asphalt binder content) (See Note 4):

$P_{sa} = 95.5$
$P_b = 4.5$
$G_{se} = 2.645$
$G_b = 1.032$

$$G_{mm} = \frac{100}{\frac{95.5}{2.645} + \frac{4.5}{1.032}} = 2.471$$

12. DETERMINATION OF DESIGN PERCENT ASPHALT BINDER CONTENT

12.1 The design percent asphalt binder content is determined as follows in Subsections 12.2 through 12.3.

12.2 For each asphalt binder content used, calculate effective voids (V_a), percent absorbed asphalt (P_{ba}), voids in mineral aggregate (VMA), percent effective asphalt binder content (P_{be}), and the ratio of the mix design composite gradation target for the No. 200 sieve, including mineral admixture, to the effective asphalt binder content (Dust/Bitumen Ratio) using the following equations.

12.2.1 Using Equation 8, calculate the effective voids (V_a). The calculated G_{mm} values for the respective asphalt binder contents are used to determine the corresponding effective voids content of the compacted Marshall specimens at each asphalt binder content.

Equation 8: $$V_a = \left(\frac{G_{mm} - G_{mb}}{G_{mm}} \right) \text{x } 100$$

Where:
- V_a = Effective voids in the compacted mixture, percent of total volume.
- G_{mm} = Calculated maximum theoretical specific gravity of the mix at each asphalt binder content P_b.
- G_{mb} = Bulk specific gravity of compacted mixture specimens.

Example (for 4.5% asphalt binder content) (See Note 4):

G_{mm} = 2.471
G_{mb} = 2.290

$$V_a = \frac{2.471 - 2.290}{2.471} \text{ x } 100 = 7.3$$

12.2.2 Using Equation 9, calculate the percent absorbed asphalt (P_{ba}).

Note 14: The percent absorbed asphalt (P_{ba}) is the same for all asphalt binder contents.

Equation 9: $$P_{ba} = \left(\frac{G_{se} - G_{sb}}{G_{sb} \ x \ G_{se}} \right) x \, G_b \ x \, 100$$

Where: P_{ba} = Absorbed asphalt, percent by total weight of mix.
G_{se} = Effective specific gravity of the combined aggregate and mineral admixture.
G_{sb} = Bulk oven dry specific gravity of the combined aggregate and mineral admixture.
G_b = Specific gravity of the asphalt binder.

Example: G_{se} = 2.645
G_{sb} = 2.614
G_b = 1.032

$$P_{ba} = \frac{2.645 - 2.614}{2.614 \ x \ 2.645} \ x \ 1.032 \ x \, 100 = 0.46$$

12.2.3 Using Equation 10, calculate voids in mineral aggregate (VMA) of the compacted Marshall specimens at each asphalt binder content.

Equation 10: $$VMA = 100 - \left(\frac{G_{mb} \ x \ P_{sa}}{G_{sb}} \right)$$

Where: VMA = Voids in the mineral aggregate, percent of bulk volume.
G_{mb} = Bulk specific gravity of compacted mixture specimens.
P_{sa} = Aggregate and mineral admixture content, percent by total weight of mix (100-P_b).
G_{sb} = Bulk oven dry specific gravity of the combined aggregate and mineral admixture.

Example (for 4.5% asphalt binder content) (See Note 4):

G_{mb} = 2.290
P_{sa} = 95.5
G_{sb} = 2.614

$$VMA = 100 - \frac{2.290 \times 95.5}{2.614} = 16.3$$

12.2.4 Using Equation 11, calculate the percent effective asphalt binder content (P_{be}) of the compacted Marshall specimens at each asphalt binder content.

Equation 11: $$P_{be} = P_b - \left(\frac{P_{ba} \times P_{sa}}{100} \right)$$

Where:
- P_{be} = Percent effective asphalt binder content of the mixture (free binder not absorbed).
- P_b = Asphalt binder content, percent by total weight of mix.
- P_{ba} = Absorbed asphalt, percent by total weight of mix.
- P_{sa} = Aggregate and mineral admixture content, percent by total weight of mix (100-P_b).

Example (for 4.5% asphalt binder content) (See Note 4):

P_b = 4.5
P_{ba} = 0.46
P_{sa} = 95.5

$$P_{be} = 4.5 - \frac{0.46 \times 95.5}{100} = 4.06$$

12.2.5 Using Equation 12, calculate the the ratio of the mix design composite gradation target for the No. 200 sieve, including mineral admixture, to the effective asphalt binder content (Dust/Bitumen Ratio) of the compacted Marshall specimens at each asphalt binder content.

Equation 12: $$\text{Dust / Bitumen Ratio} = \frac{\begin{bmatrix} \text{Mix Design} \\ \text{Passing No. 200} \\ \text{(Including Mineral Admix.)} \end{bmatrix}}{P_{be}}$$

Where: P_{be} = Percent effective asphalt binder content of the mixture (free binder not absorbed).

Example (for 4.5% asphalt binder content) (See Note 4):

$$P_{be} = 4.06$$

$$\text{Dust / Bitumen Ratio} = \frac{5.0}{4.06} = 1.23$$

12.3 If the specified value for effective voids (V_a) falls between the resultant V_a values determined for two of the asphalt binder contents used, straight-line interpolation shall be used to calculate the bulk specific gravity (G_{mb}) at each 0.1% asphalt binder content increment between the two corresponding measured values of G_{mb}. Using equations 7 and 8, determine the values for G_{mm} and V_a at each interpolated asphalt binder content. Select the asphalt binder content which results in V_a being as close as possible to the specified value.

12.3.1 Using equations 10, 11, and 12, calculate VMA, P_{be}, and the Dust/Bitumen Ratio at the selected asphalt binder content. Using straight-line interpolation, determine the values for stability and flow that correspond to the selected asphalt binder content. If the values for VMA, Dust/Bitumen Ratio, stability, and flow are within the limits of the specifications, the selected asphalt binder content shall be the design asphalt binder content.

12.3.2 On separate graphs (using the same scale for percent asphalt binder for each graph), plot the values for bulk specific gravity, effective voids, VMA, Dust/Bitumen Ratio, stability, and flow for each set of three specimens and at the design asphalt binder content, versus the percent asphalt binder. Draw a smooth "best fit" curve based on the plotted points, as shown in Figure 4. The graphs in Figure 4 are for illustrative purposes only. Straight-line interpolation, as specified in Subsections 12.3 and 12.3.1, is used for mix design calculations.

12.3.3 If it is not possible to obtain specification compliance within the range of asphalt binder contents used, a determination must be made to either redesign the mix (different aggregate gradation and/or source) or prepare additional specimens at other asphalt binder contents for testing and volumetric analyses.

13. IMMERSION COMPRESSION (IMC) TEST

13.1 The Immersion Compression Test shall be performed in accordance with ARIZ 802, modified as follows:

13.1.1 Prepare the asphaltic concrete sample including mineral admixture according to the procedures described in Section 5 and Subsections 8.2 through 8.5 at the design asphalt binder content.

13.1.2 Immediately after mixing, each batch of asphaltic concrete shall be thoroughly blended and spread according to the procedures described in ARIZ 416. The circular mass shall be cut into 4 equal pie-shaped segments. Take opposite segments for each individual sample and use up the entire batch.

13.1.3 Each individual sample shall be spread in a large pan at nominal single-stone thickness. Avoid stacking particles as feasible. The samples shall be oven-cured for 2 hours ± 10 minutes at 255 ± 5 ºF.

13.1.4 Compacted specimens shall be 4.000 ± 0.100 inches in height.

14. MIX DESIGN GRADATION TARGET VALUES

14.1 The target values for the aggregate composite without mineral admixture, and the aggregate-mineral admixture blend composite, for the asphaltic concrete mixture shall be expressed as percent passing particular sieve sizes as required by the specifications for the project. An example mix design composite, with and without mineral admixture, is shown in Figure 1.

15. REPORT

15.1 Report the test results and data obtained on the appropriate form. Liberal use of the remarks area to clarify and/or emphasize any element of the design is strongly recommended. Information required in the mix design report includes the items listed below:

15.1.1 Name and address of the testing organization and the signature and seal of the mix design engineer responsible for the mix design.

15.1.2 Aggregate:

- Source and identification
- Individual stockpile or bin gradations
- Aggregate blend proportions and composite gradation, with and without mineral admixture
- Fine and coarse aggregate specific gravities (Bulk Oven Dry, SSD, Apparent) and absorption
- Combined aggregate specific gravities (Bulk Oven Dry, SSD, Apparent)
- Combined aggregate absorption
- Aggregate quality
    - LA Abrasion
    - Sand Equivalent
    - Fractured Coarse Aggregate Particles (percentage with one fractured face and percentage with two fractured faces)
    - Uncompacted Void Content (when applicable)
    - Carbonates (when applicable)

15.1.3 Mineral Admixture:

- Type and source
- Percentage used
- Specific gravity

15.1.4 Combined Mineral Aggregate and Mineral Admixture

- Combined specific gravities [Bulk Oven Dry (G_{sb}), SSD, Apparent] and absorption of the combined aggregate and mineral admixture
- Effective specific gravity of the combined aggregate and mineral admixture (G_{se})

15.1.5 Asphalt Binder:

- Source and grade
- Specific gravity (at 77 °F)
- Viscosity - Temperature Curve and the following:
    - Laboratory mixing temperature range and actual laboratory mixing temperature used.
    - Laboratory compaction temperature range and actual laboratory compaction temperature used.

15.1.6 Maximum theoretical specific gravity (G_{mm}) and density (pcf) at the asphalt binder content at which the Rice test was performed (Rice P_b)

15.1.7 Mixture Compaction Trials:

- Percent asphalt binder content (P_b), by weight of the bituminous mixture
- Aggregate and mineral admixture content (P_{sa})
- Calculated maximum theoretical specific gravity (G_{mm}) and density (pcf)
- Bulk specific gravity (G_{mb}) and bulk density (pcf) of Marshall specimens
- Percent effective voids (V_a)
- Percent voids in mineral aggregate (VMA)
- Dust/Bitumen Ratio
- Percent absorbed asphalt (P_{ba})
- Percent effective asphalt binder content (P_{be})
- Marshall stability (nearest 10 pounds)
- Marshall flow (0.01 inch)

15.1.8 Plots of the following properties versus percent asphalt binder content (See examples in Figure 4):

- Percent effective voids (V_a)
- Percent voids in mineral aggregate (VMA)
- Dust/Bitumen Ratio
- Bulk specific gravity (G_{mb})
- Marshall stability
- Marshall flow

15.1.9 Mixture Properties at Design Percent Asphalt Binder Content:

- Percent asphalt binder content (P_b), by weight of the bituminous mixture
- Aggregate and mineral admixture content (P_{sa})
- Calculated maximum theoretical specific gravity (G_{mm}) and density (pcf)
- Bulk specific gravity (G_{mb}) and bulk density (pcf) of Marshall specimens
- Percent effective voids (V_a)
- Percent voids in mineral aggregate (VMA)
- Dust/Bitumen Ratio
- Percent absorbed asphalt (P_{ba})
- Percent effective asphalt binder content (P_{be})
- Marshall stability (nearest 10 pounds)
- Marshall flow (0.01 inch)
- Immersion Compression wet strength (psi)
- Immersion Compression dry strength (psi)
- Index of retained strength

15.1.10 Mix Design Summary. The mix design summary shall contain the information shown in Figure 5. [An example Mix Design Summary for an Asphaltic Concrete Marshall Mix Design.]

Example Mix Design Composite
(With and Without Mineral Admixture)

Material	Crusher Fines	Washed Crusher Fines	3/8" Aggregate	3/4" Aggregate	Composite		Specifications ADOT 416 (3/4 Inch Special Mix)	
Percent used in composite	10	27	30	33	Without Admix	With Admix*	Without Admix	With Admix
Sieve	Gradation – Percent Passing							
1"	100.0	100.0	100.0	100.0	100	100	100	100
3/4"	100.0	100.0	100.0	82.5	94	94	90 - 100	90 - 100
1/2"	100.0	100.0	100.0	33.3	78	78		
3/8"	100.0	100.0	96.1	15.7	71	71	62 - 77	62 - 77
1/4"	100.0	99.9	81.0	5.3	63	63		
#4	91.6	98.8	73.1	4.1	59	59		
#8	58.0	76.9	54.2	2.8	44	45	37 - 46	38 - 47
#10	52.0	68.9	50.2	2.7	40	41		
#16	37.9	48.5	39.0	2.2	29	30		
#30	26.9	30.9	28.4	1.9	20	21		
#40	21.9	22.0	23.1	1.8	16	17	10 - 18	11 - 19
#50	17.8	15.2	18.9	1.6	12	13		
#100	11.7	5.1	12.7	1.3	7	8		
#200	7.6	1.8	8.2	0.9	4.0	5.0	1.5 - 4.5	2.5 – 6.0

* 1.0 percent admixture, by weight of dry mineral aggregate, is used.

FIGURE 1

Example Weigh Up Sheet #1

MATERIAL	SIEVE	INDIV. % RET.	ACCUM. % RET.	FRACTURED COARSE AGGREGATE PARTICLES [Plus #4] (500 grams)	COARSE AGGREGATE SPECIFIC GRAVITY/ ABSORPTION [Plus #4] (4000 grams)	FINE AGGGREGATE SPECIFIC GRAVITY/ ABSORPTION [Minus #4] (1200 grams)	SAND EQUIVALENT [Minus #4] (600 grams)	UNCOMPACTED VOID CONTENT [Minus #8] (500 grams)	ABRASION [Type B] (5000 grams)
				ACCUMULATIVE WEIGHT (grams)					
Crusher Fines	#4	0.840	0.840	10	82	---	---	---	---
	#8	3.360	4.200	---	---	68	34	---	---
	- #8	5.800	10.000	---	---	186	93	66	---
Washed Crushed Fines	1/4"	0.027	10.027	11	85	---	---	---	---
	#4	0.297	10.324	14	114	---	---	---	---
	#8	5.913	16.237	---	---	306	153	---	---
	- #8	20.763	37.000	---	---	727	364	304	---
3/8" Aggregate	3/8"	1.170	38.170	29	228	---	---	---	419
	1/4"	4.530	42.700	84	672	---	---	---	---
	#4	2.370	45.070	113	904	---	---	---	---
	#8	5.670	50.740	---	---	842	421	---	---
	- #8	16.260	67.000	---	---	1173	586	489	---
1/2" Aggregate	3/4"	5.775	72.775	184	1469	---	---	---	---
	1/2"	16.236	89.011	382	3057	---	---	---	2919
	3/8"	5.808	94.819	453	3625	---	---	---	5000
	1/4"	3.432	98.251	495	3961	---	---	---	---
	#4	0.396	98.647	500	4000	---	---	---	---
	#8	0.429	99.076	---	---	1181	590	---	---
	- #8	0.924	100.000	---	---	1200	600	500	---

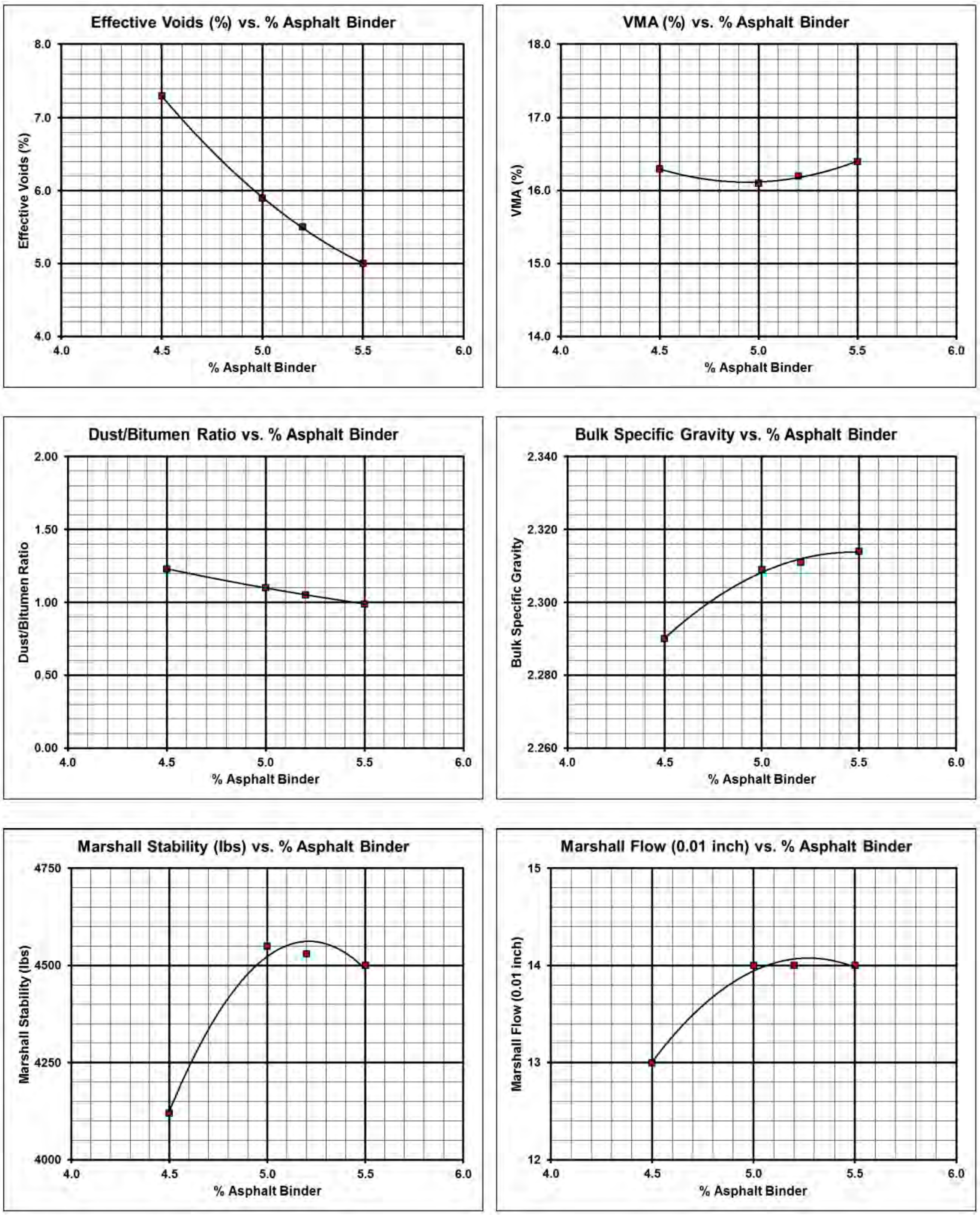
FIGURE 2

Example Weigh Up Sheet #2

MATERIAL	SIEVE	INDIV. PERCENT RETAINED	ACCUM. PERCENT RETAINED	RICE (3000 grams)	MARSHALL (3300 grams)	IMMERSION COMPRESSION (3400 grams)	MINUS NO. 8 MAKE-UP MATERIAL (500 grams)
				ACCUMULATIVE WEIGHT (grams)			
Crusher Fines	#4	0.840	0.840	25	28	29	---
	#8	3.360	4.200	126	139	143	---
	- #8	5.800	10.000	300	330	340	66
Washed Crusher Fines	1/4"	0.027	10.027	301	331	341	---
	#4	0.297	10.324	310	341	351	---
	#8	5.913	16.237	487	536	552	---
	- #8	20.763	37.000	1110	1221	1258	304
3/8" Aggregate	3/8"	1.170	38.170	1145	1260	1298	---
	1/4"	4.530	42.700	1281	1409	1452	---
	#4	2.370	45.070	1352	1487	1532	---
	#8	5.670	50.740	1522	1674	1725	---
	- #8	16.260	67.000	2010	2211	2278	489
3/4" Aggregate	3/4"	5.775	72.775	2183	2402	2474	---
	1/2"	16.236	89.011	2670	2937	3026	---
	3/8"	5.808	94.819	2845	3129	3224	---
	1/4"	3.432	98.251	2948	3242	3341	---
	#4	0.396	98.647	2959	3255	3354	---
	#8	0.429	99.076	2972	3270	3369	---
	- #8	0.924	100.000	3000	3300	3400	500
Weight of Mineral Admixture (Type II Cement) [1.0%, by weight of Dry Mineral Aggregate]				30	33	34	---
Total weight of Mineral Aggregate and Mineral Admixture				3030	3333	3434	---

FIGURE 3

Example Plots of Effective Voids, VMA, Dust/Bitumen Ratio, Bulk Specific Gravity, Marshall Stability, and Marshall Flow versus Percent Asphalt Binder Content



The above graphs are for illustrative purposes only. Straight-line interpolation, as specified in Subsections 12.3 and 12.3.1, is used for mix design calculations.

FIGURE 4

Asphaltic Concrete Marshall Mix Design
Example Mix Design Summary

Date: February 22, 2013

Contractor: Best Paving Contractors, Inc.	**Mix Designation:** ADOT 416 (3/4 Inch Special Mix)
ADOT Project Number: STP-888-Z(888)A	**Mix Design Laboratory:** XYZ Testing Laboratories
ADOT TRACS Number: H888801C	**Mix Design Engineer:** Joe Designer
Project Name: Anywhere - Everywhere	**Grade/Specific Gravity of Asphalt Binder:** PG 70-10/1.032 @

COMPOSITE GRADATION:

Mineral Aggregate	Percent Used
Crusher Fines	10
Washed Crusher Fines	27
3/8" Aggregate	30
3/4" Aggregate	33
Mineral Admixture	
Type II Cement	1.0

Sieve Size	Percent Passing w/o Admix	Percent Passing w/ Admix	Specifications Without Admix	Specifications With Admix
1"	100	100	100	100
3/4"	94	94	90 - 100	90 - 100
1/2"	78	78		
3/8"	71	71	62 - 77	62 - 77
1/4"	63	63		
#4	59	59		
#8	44	45	37 - 46	38 - 47
#10	40	41		
#16	29	30		
#30	20	21		
#40	16	17	10 - 18	11 - 19
#50	12	13		
#100	7	8		
#200	4.0	5.0	1.5 - 4.5	2.5 - 6.0

DESIGN DATA:

% Asphalt Binder	4.5	5.0	**5.2**	5.5	Spec.
Bulk Specific Gravity	2.290	2.309	**2.311**	2.314	
Bulk Density (lb./cu. ft)	142.7	143.9	**144.0**	144.2	
Stability (lb.)	4120	4550	**4530**	4500	2000 Min.
Flow (0.01 inch)	13	14	**14**	14	8 - 16
Effective Voids (%)	7.3	5.9	**5.5**	5.0	5.5 ± 0.2
VMA (%)	16.3	16.1	**16.2**	16.4	15.0 - 18.0
Effective Asphalt, Total Mix (%)	4.06	4.56	**4.76**	5.06	
Dust/Bitumen Ratio	1.23	1.10	**1.05**	0.99	0.6 – 1.2
Absorbed Asphalt (%)	0.46				0 – 1.0

Max. Theoretical Specific Gravity at 5.2% Asphalt Binder = 2.446

Max. Theoretical Density at 5.2% Asphalt Binder = 152.4 lb/cu. ft.

IMMERSION COMPRESSION – ARIZ 802: 5.2% Asphalt Binder, 1.0% Type II Cement		Spec.
Dry Strength (psi)	728	-----
Wet Strength (psi)	627	150 Min.
Index of Retained Strength (%)	86	60 Min.

AGGREGATE PROPERTIES:

Test Characteristic	Fine	Coarse	Combined	Spec.
Bulk O.D. Specific Gravity	2.593	2.634	2.610	2.350 – 2.850
SSD Specific Gravity	2.626	2.655	2.638	-----
Apparent Specific Gravity	2.682	2.690	2.685	-----
Absorption	1.28	0.79	1.08	0 - 2.5%
Sand Equivalent	75			Min. 55
Uncompacted Void Content	47.4			Min. 45.0%
Carbonates	N/A			-----
Fractured Coarse Aggregate Particles				
At least one fractured face	100			Min. 92%
At least two fractured faces	95			Min. 85%
Abrasion	(Type B)			
100 Rev., % Loss	4			9% Max.
500 Rev. ,%Loss	22			40% Max.

RECOMMENDED ASPHALT BINDER CONTENT: (By weight of total mix)	**5.2%**

COMBINED AGGREGATE AND MINERAL ADMIXTURE PROPERTIES:

Bulk O.D.Specific Gravity	2.614
SSD Specific Gravity	2.642
Apparent Specific Gravity	2.689
Water Absorption	1.07
Effective Specific Gravity	2.645

ADDITIONAL DATA / INFORMATION:

- Source of Mineral Aggregate: Excellent Aggregate Materials, Inc.
- Source of Asphalt Binder: Superb Asphalt Suppliers
- Source of Mineral Admixture: Superior Cement Company, Inc.
- Mineral Admixture Type/Specific Gravity: Type II Cement/3.14
- Laboratory Mixing Temperature Range: 320 °F to 331 °F
- Laboratory Compaction Temperature Range: 298 °F to 307 °F
- Actual Laboratory Mixing Temperature Used: 325 °F
- Actual Laboratory Compaction Temperature Used: 300 °F

REMARKS:

FIGURE 5

MARSHALL MIX DESIGN METHOD FOR ASPHALTIC CONCRETE (ASPHALT-RUBBER) [AR-AC]

(An Arizona Method)

1. SCOPE

1.1 This method is used to design Asphaltic Concrete (Asphalt-Rubber) [AR-AC] mixes using 4-inch diameter Marshall apparatus.

1.2 This test method involves hazardous material, operations, and equipment. This test method does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1.3 See Appendix A1 of the Materials Testing Manual for information regarding the procedure to be used for rounding numbers to the required degree of accuracy.

1.4 A listing of subsequent Sections and Figures in this procedure is given below:

Section or Figure #	Title	Page #
Section 2	Test Methods and Apparatus	2
Section 3	Materials	3
Section 4	Determination of Composite Gradation	4
Section 5	Preparing Aggregate/Mineral Admixture Samples for Mix Design Testing	4
Section 6	Aggregate Specific Gravities and Absorption	7
Section 7	Preparation of Specimens for Bulk Specific Gravity/Bulk Density and Marshall Stability/Flow Determination	9
Section 8	Bulk Specific Gravity/Bulk Density of Specimens	13
Section 9	Marshall Stability and Flow Determination	14
Section 10	Maximum Theoretical Specific Gravity (Rice Test)	14
Section 11	Determination of Design Percent CRA Binder Content	16
Section 12	Mix Design Gradation Target Values	19
Section 13	Report	20
Figure 1	Example Mix Design Composite (With and Without Mineral Admixture)	23
Figure 2	Example Weigh Up Sheet #1	24
Figure 3	Example Weigh Up Sheet #2	25
Figure 4	Example Plots of Effective Voids, VMA, Bulk Specific Gravity, Marshall Stability, and Marshall Flow versus Percent CRA Binder Content	26
Figure 5	Example Mix Design Summary	27 & 28

2. TEST METHODS AND APPARATUS

2.1 This test method is used in conjunction with the test methods listed below. Requirements for the frequency of equipment calibration and verification are found in Appendix A3 of the Materials Testing Manual. The required apparatus is shown in the individual test methods, as appropriate.

2.2 Arizona Test Methods:

- ARIZ 201 Sieving of Coarse and Fine Graded Soils and Aggregates
- ARIZ 205 Composite Grading
- ARIZ 210 Specific Gravity and Absorption of Coarse Aggregate
- ARIZ 211 Specific Gravity and Absorption of Fine Aggregate
- ARIZ 212 Percentage of Fractured Coarse Aggregate Particles
- ARIZ 238 Percent Carbonates in Aggregate
- ARIZ 247 Particle Shape and Texture of Fine Aggregate Using Uncompacted Void Content
- ARIZ 248 Alternate Procedures for Sieving of Coarse and Fine Graded Soils and Aggregates
- ARIZ 251 Combined Coarse and Fine Aggregate Specific Gravity and Absorption
- ARIZ 410 Compaction and Testing of Bituminous Mixtures Utilizing Four Inch Marshall Apparatus
- ARIZ 415 Bulk Specific Gravity and Bulk Density of Compacted Bituminous Mixtures
- ARIZ 416 Preparing and Splitting Field Samples of Bituminous Mixtures for Testing
- ARIZ 806 Maximum Theoretical Specific Gravity of Laboratory Prepared Bituminous Mixtures (Rice Test)

2.1.2 AASHTO Test Methods:

- AASHTO T 96 Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
- AASHTO T 176 Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
- AASHTO T 228 Specific Gravity of Semi-Solid Bituminous Materials

Note 1: Testing by AASHTO T 228 shall be performed at 77 °F.

3. MATERIALS

3.1 Mineral Aggregate - The mineral aggregate used in the design shall be produced material from the source(s) for the project. Use of natural sand is not permitted in AR-AC mixtures.

3.1.1 The composited gradation of the aggregate without admixture, and the composited gradation of the aggregate-mineral admixture blend shall comply with the grading limits of the specifications.

3.1.2 The composited mineral aggregate shall conform to the requirements of the specifications for Sand Equivalent (AASHTO T 176), Combined Bulk Oven Dry Specific Gravity (ARIZ 251), Combined Water Absorption (ARIZ 251), Fractured Coarse Aggregate Particles (ARIZ 212), Uncompacted Void Content (ARIZ 247), and Percent Carbonates (ARIZ 238) when applicable.

3.1.3 Mineral aggregate from each source shall be tested separately for compliance to the project requirements for Abrasion (AASHTO T 96).

3.2 Bituminous Material - The bituminous material used in the design shall be asphalt-rubber material [hereinafter Crumb Rubber Asphalt (CRA)], conforming to the requirements of Section 1009 of the specifications, which is to be used in the production of the AR-AC. The specific gravity of the CRA and of the asphalt cement used in the CRA shall be determined in accordance with AASHTO T 228 (at 77 °F).

3.3 Mineral Admixture - Mineral admixture is required. The mineral admixture used in the design shall be the same type of material to be used in production of the AR-AC. The mineral admixture shall conform to the requirements of the specifications.

3.4 Batch Plants - Mix designs developed for asphaltic concrete which is to be produced in a batch plant shall be prepared in accordance with this procedure, modified as follows:

3.4.1 Aggregate samples will be obtained from the hot bins for all testing except Sand Equivalent. Testing for Sand Equivalent will be performed on aggregate stockpile samples proportioned and composited to meet the mix design composite without admixture. Any method may be used to combine the aggregate stockpile samples for Sand Equivalent testing as long as the resultant gradation is representative of the mix design composite gradation without admixture.

3.4.2 The mix design shall provide component percentages and composite gradations for both stockpile and hot bin materials.

4. DETERMINATION OF COMPOSITE GRADATION

4.1 The gradation of the aggregate from each individual component stockpile or bin shall be determined in accordance with ARIZ 248 using washed sieve analysis Alternate #3, Alternate #4, or Alternate #5. For Alternate #5, washing of the coarse aggregate may be performed on the composite Plus No. 4 material and applied to the composite percent pass the minus No. 200 determined from the unwashed coarse sieving and washed fine sieving of the individual stockpiles.

4.2 The composite gradation of the mineral aggregate is determined using desired percentages of each component based on washed sieve analysis. Mix designs may be developed based on bin or stockpile material, as appropriate for the respective mix production facility to be used.

4.3 The mineral aggregate composite shall be determined in accordance with ARIZ 205, paragraph 2(e).

4.4 The aggregate-mineral admixture blend composite is determined by adjusting the mineral aggregate composite (percent passing) for mineral admixture by performing the calculation in Equation 1 for each sieve:

Equation 1:

$$\left(\begin{array}{c}\text{\% passing} \\ \text{each sieve} \\ \text{[Adjusted for} \\ \text{Mineral} \\ \text{Admixture]}\end{array}\right) = \frac{\left(\begin{array}{c}\text{\% passing} \\ \text{each sieve in} \\ \text{the aggregate} \\ \text{composite}\end{array}\right) + \left(\begin{array}{c}\text{\% Mineral} \\ \text{Admixture}\end{array}\right)}{(100) + (\text{\% Mineral Admixture})} \times 100$$

4.5 The composited gradation of the aggregate and the composited gradation of the aggregate-mineral admixture blend shall be shown on the design report, along with the percentage of each material.

5. PREPARING AGGREGATE/MINERAL ADMIXTURE SAMPLES FOR MIX DESIGN TESTING

5.1 Based on the stockpile or bin composite aggregate gradation, the aggregate samples needed for mix design tests are prepared as follows.

5.1.1 Dry the mineral aggregate from each individual stockpile at a temperature not exceeding any temperature restrictions specified in subsequent test procedures. Drying shall be performed until no further weight loss is obtained from continued drying.

5.1.2 Representative samples of aggregate material which is retained on the individual No. 8 and larger sieve sizes and the minus No. 8 material from each stockpile or bin are used to prepare the samples for mix design testing.

5.1.3 Table 1 shows the aggregate sample sizes, the number of samples required for each test listed, and which samples include mineral admixture. The aggregate weight shown for Maximum Theoretical Specific Gravity will provide three Rice test specimens and the amount shown for Density-Stability/Flow will produce three Marshall specimens. Example weigh-up sheets are shown in Figures 2 and 3.

Table 1

Sample Type	**Sample Size**	**Number of Samples**
Fractured Coarse Aggregate Particles (ARIZ 212)	Required grams of Mineral Aggregate as determined by test method [No mineral admixture]	1
Percent Carbonates (ARIZ 238) (When required)	300 grams of Mineral Aggregate [No mineral admixture]	1
Abrasion (AASHTO T 96)	5000 grams of Mineral Aggregate as per test method for grading type [No mineral admixture]	1
Fine Aggregate Specific Gravity/ Absorption (ARIZ 211)	1200 grams of Mineral Aggregate [No mineral admixture]	1
Coarse Aggregate Specific Gravity/Absorption (ARIZ 210)	Required grams of Mineral Aggregate as determined by the Nominal Maximum Aggregate Size [No mineral admixture]	1
Sand Equivalent (AASHTO T 176)	500 to 750 grams of Mineral Aggregate [No mineral admixture]	1

Table 1 (Continued)		
Uncompacted Void Content (ARIZ 247)	Minimum 500 grams of Mineral Aggregate [No mineral admixture]	1
Minus No. 8 Make-Up Material	An adequate amount (normally 500 grams) of Mineral Aggregate [No mineral admixture]	1
Marshall Density-Stability/Flow (ARIZ 415 and ARIZ 410, as modified in Sections 8 and 9 respectively)	3000 grams of Mineral Aggregate (See Note 2) [Plus 30 grams of mineral admixture]	3 (See Note 3) [Each sample yields 1 set of 3 Marshall Specimens]
Maximum Theoretical Specific Gravity (Rice Test) (ARIZ 806, as modified in Section 10)	3000 grams of Mineral Aggregate [Plus 30 grams of mineral admixture]	1 [Yields 3 test specimens]

Note 2: Generally 3000 grams of mineral aggregate will provide Marshall Density-Stability/Flow specimens of acceptable heights, but adjustments may be necessary in some cases. Use Equation 2 to adjust the weight of aggregate as necessary to conform to specimen height requirements of 2.500 ± 0.200 inches.

***Equation 2*:** $$\text{Adjusted Weight of Aggregate} = \frac{\left(\begin{array}{c}\text{Combined Bulk O.D.}\\ \text{Agg. Specific Gravity}\end{array}\right)}{2.650} \text{ x } 3000$$

Note 3: Requires one sample for each CRA binder content to be tested (minimum of three CRA binder contents, with three Marshall specimens at each CRA binder content).

5.1.4 After the aggregate samples for the Marshall and Rice specimens have been composited, add 1% mineral admixture, by dry weight of the aggregate, and mix thoroughly. Add 3% water, by dry weight of the aggregate, to each sample and mix thoroughly to wet the mineral admixture and aggregate surfaces.

5.1.5 Testing utilizing the prepared virgin aggregate-mineral admixture samples for Marshall and Rice will be performed as specified in Sections 7-9 and 10, respectively.

6. AGGREGATE SPECIFIC GRAVITIES AND ABSORPTION

6.1 Determine the Bulk Oven Dry, S.S.D., Apparent Specific Gravities and Absorption for the fine aggregate (minus No. 4) and the coarse aggregate (plus No. 4) in accordance with ARIZ 211 and ARIZ 210, respectively.

6.2 Determine the combined bulk oven dry specific gravity of the fine aggregate and the coarse aggregate without mineral admixture and also the combined water absorption of the fine aggregate and the coarse aggregate without mineral admixture, in accordance with ARIZ 251.

6.2.1 The combined aggregate bulk oven dry specific gravity without mineral admixture and the combined aggregate water absorption without mineral admixture are used only to determine compliance with specification requirements.

6.3 Using Equation 3, calculate the Combined Bulk Oven Dry (Gsb), S.S.D., and Apparent Specific Gravities of the aggregate-mineral admixture blend.

Equation 3:

$$\begin{pmatrix}\text{Combined Specific Gravity} \\ \text{of Aggregate and Mineral} \\ \text{Admixture Blend}\end{pmatrix} = \frac{P_f + P_c + P_{admix}}{\frac{P_f}{G_f} + \frac{P_c}{G_c} + \frac{P_{admix}}{G_{admix}}}$$

Where:

P_f, P_c = Weight percent of fine aggregate (minus No. 4) and coarse aggregate (plus No. 4) respectively. Determined from the aggregate composite without mineral admixture.

P_{admix} = Percent mineral admixture by weight of the aggregate.

$P_f + P_c$ = 100

$P_f + P_c + P_{admix}$ = 100 + % Mineral Admixture

G_f, G_c = Bulk Oven Dry, S,S.D., or Apparent specific gravity of the fine aggregate and the coarse aggregate respectively.

G_{admix} = Specific gravity of the mineral admixture.

Type I or II Cement	=	3.14
Type IP Cement	=	3.00
Hydrated Lime	=	2.20

Example [for combined Bulk Oven Dry Specific Gravity (G_{sb})]:

P_f = 38
P_c = 62
G_f = 2.732
G_c = 2.772
G_{admix} = 2.20 (Hydrated Lime)
P_{admix} = 1.0

$$\left[\begin{array}{l}\text{Example of Combined} \\ \text{Bulk Oven Dry Specific} \\ \text{Gravity } (G_{sb}) \text{ of Aggregate} \\ \text{and Mineral Admixture}\end{array}\right] = \frac{38 + 62 + 1.0}{\frac{38}{2.732} + \frac{62}{2.772} + \frac{1.0}{2.20}} = 2.750$$

6.4 Using Equation 4, calculate the Combined Water Absorption of the aggregate-mineral admixture blend.

Equation 4:

$$\left(\begin{array}{l}\text{Combined Water Absorption} \\ \text{of Aggregate and Mineral} \\ \text{Admixture Blend}\end{array}\right) = \frac{(P_f \text{ x } A_f) + (P_c \text{ x } A_c) + (P_{admix} \text{ x } A_{admix})}{P_f + P_c + P_{admix}}$$

Where: P_f, P_c = Weight percent of fine aggregate (minus No. 4) and coarse aggregate (plus No. 4) respectively. Determined from the aggregate composite without mineral admixture.

P_{admix} = Percent mineral admixture by weight of the aggregate.

$P_f + P_c$ = 100

$P_f + P_c + P_{admix}$ = 100 + % Mineral Admixture

A_f, A_c = Percent water absorption of the coarse aggregate and the fine aggregate respectively.

A_{admix} = Percent water absorption of mineral admixture (<u>assumed to be 0.0%</u>).

Example:

$P_f = 38$
$P_c = 62$
$A_f = 2.42$
$A_c = 1.68$
$P_{admix} = 1.0$
$A_{admix} = 0.00$

$$\begin{bmatrix}\text{Combined Water}\\ \text{Absorption of}\\ \text{Aggregate and}\\ \text{Mineral Admixture}\end{bmatrix} = \frac{(38 \times 2.42) + (62 \times 1.68) + (1.0 \times 0.00)}{38 + 62 + 1.0} = 1.94$$

7. PREPARATION OF SPECIMENS FOR BULK SPECIFIC GRAVITY/BULK DENSITY AND MARSHALL STABILITY/FLOW DETERMINATION

7.1 Specimens shall be prepared as described herein, utilizing the apparatus specified in ARIZ 410.

Note 4: Normally a range of 3 different CRA binder contents at 1.0% increments will provide sufficient information, although in some cases it may be necessary to prepare additional sets of samples at other CRA binder contents. Two series of CRA binder contents are customarily used: either 6.0%, 7.0%, and 8.0% CRA by total mix weight; or 6.5%, 7.5%, and 8.5% CRA by total mix weight.

7.2 The aggregate-mineral admixture samples, prepared as specified in Section 5, shall be dried to constant weight at 325 ± 5 ºF and shall be at this temperature at the time of mixing with the CRA. If necessary, a small amount of proportioned minus No. 8 aggregate make-up material shall be added to bring samples to the desired weight.

7.3 Before each batch of AR-AC is mixed, the CRA shall be heated in a loosely covered container in a forced draft oven for approximately 2 hours or as necessary to reach a temperature of 325 ± 5 ºF (See ***CAUTION*** below). Upon removal from the oven, the CRA shall be thoroughly stirred to uniformly distribute the rubber particles throughout the CRA before adding the designated proportion to the aggregate-mineral admixture blend. If there is any delay before beginning of mixing the CRA with the aggregate-mineral admixture blend, thoroughly stir the CRA again immediately before pouring.

CAUTION: ***To avoid damage to the CRA, a hot plate or open flame is not used to bring it to the specified temperature. Once the CRA temperature has reached 325 ± 5 ºF, the container may briefly be moved to a hot plate for no more than 5 minutes at at time to maintain that temperature. If a hot plate is utilized, a suitable shield, baffle plate, or sand bath shall be used on the surface of the hot plate to minimize localized overheating. The CRA shall be constantly stirred to avoid sticking or scorching. Do not heat the CRA longer than necessary to complete batching and mixing operations (approximately three hours total heating time), or damage may occur.***

7.4 Using Equation 5, calculate the weight of CRA to be used for each CRA binder content:

Equation 5:

$$\begin{bmatrix} \text{Weight of} \\ \text{CRA} \end{bmatrix} = \frac{\begin{bmatrix} \text{Weight of Aggregate} \\ \text{and Mineral Admixture} \end{bmatrix}}{100 - \begin{bmatrix} \text{Percent of} \\ \text{CRA} \end{bmatrix}} \times \begin{bmatrix} \text{Percent of} \\ \text{CRA} \end{bmatrix}$$

Example (for Marshall specimens with 7.5% CRA) (See Note 4):

$$\begin{bmatrix} \text{Weight of} \\ \text{CRA} \end{bmatrix} = \frac{3030}{100 - 7.5} \times 7.5 = 245.7 \text{ grams}$$

Note 5: Before each batch is mixed, the mixing bowl and whip shall be heated to 325 ± 5 ºF.

7.5 The aggregate-mineral admixture blend and the appropriate amount of CRA shall be mixed together for 90 to 120 seconds at the required mixing temperature of 325 ± 5 ºF. **Mechanical mixing is required.**

Note 6: Although a wide range of mixers may provide the desired well-coated homogeneous mixture, commercial dough mixers with whips are often used. Minimum recommended capacity of the mixing bowl is 12 quarts.

Note 7: After mechanical mixing, hand mixing shall be used as necessary to produce a well-coated homogeneous mixture.

7.6 Immediately after mixing, each batch of AR-AC shall be thoroughly blended and spread according to the procedures described in ARIZ 416. The circular mass shall be cut into 6 equal pie-shaped segments. Take opposite segments for each individual specimen and use up the entire batch.

7.7 Each individual AR-AC specimen shall be spread in a large pan at nominal single-stone thickness. Avoid stacking particles as feasible. The specimens shall be oven-cured for 2 hours ± 10 minutes at 325 ± 5 ºF.

7.8 A mold assembly (base plate, mold, and collar) shall be heated to approximately 325 ± 5 ºF. The face of the compaction hammer shall be thoroughly cleaned and heated on a hot plate set at 325 ± 5 ºF. A suitable shield, baffle plate, or sand bath shall be used on the surface of the hot plate to minimize localized overheating of the face of the hammer.

7.9 Place a 4-inch diameter paper disc in the bottom of the mold before the mixture is introduced. Quickly place the mixuture into the mold using a transfer bowl or other suitable device. Spade the mixture vigorously with a heated flat metal spatula, with a blade approximately 1-inch wide and 6-inches long and stiff enough to penetrate the entire layer of material, 15 times around the perimeter and 10 times at random into the mixture, penetrating the mixture to the bottom of the mold. Smooth the surface of mix to a slightly rounded shape.

Note 8: To ease removal of the end papers after compaction, they may be sprayed with a light application of aerosol based vegetable oil. PAM® cooking spray has been found to work well for this application.

7.10 Before compaction, put the mold containing the mixture in an oven as necessary to heat the mixture to the proper compaction temperature of 325 ± 5 ºF. The specimen shall not be heated for more than one hour after being placed in the mold. Prior to compaction, it shall be verified that the mixture is at the required temperature. An electronic temperature probe with a digital display or a long-stem metal thermometer with a dial face shall be used. The use of an infrared temperature gun is not allowed.

7.11 Immediately upon removing the mold assembly loaded with mix from the oven, place a paper disc on top of mixture, place the mold assembly on the compaction pedestal in the mold holder, and apply 75 blows with the compaction hammer. Remove the base plate and collar, and reverse and reassemble the mold. Apply 75 compaction blows to the face of the reversed specimen.

Note 9: The compaction hammer shall apply only one blow after each fall, that is, there shall not be a rebound impact. The compaction hammer shall meet the requirements specified in Subsection 2.4 of ARIZ 410.

7.12 Remove the collar and top paper disc. Remove the base plate and remove the bottom paper disc while the specimen is still hot. Replace the base plate immediately, making sure to keep the mold and specimen oriented so that the bottom face of the compacted specimen remains directly in contact with, and is fully supported by, the base plate.

Note 10: Paper discs need to be removed while the AR-AC specimen is hot. The discs are very difficult to remove after the specimens have cooled.

7.13 If any part of the top surface of a compacted specimen is visually observed to increase in height (rise or swell in the mold) after compaction, stop testing and discard the prepared specimens. Adjust the gradation of the aggregate-mineral admixture blend to provide additional void space to accommodate the CRA, then batch and compact new trial AR-AC specimens. If no visible increase in height occurs, proceed with Subsections 7.14 through 7.17.

7.14 Allow each compacted specimen to cool in a vertical position in the mold (with the base plate on the bottom and the top surface exposed to air) until they are cool enough to be extruded without damaging the specimen. Rotate the base plate occasionally to prevent sticking.

Note 11: Generally specimens can be extruded without damage when they are at a temperature of approximately 77 to 90 ºF.

Note 12: Cooling may be accomplished at room temperature, or in a 77 ºF air bath. If more rapid cooling is desired, the mold and specimen may be placed in front of a fan until cool, ***but do not turn the mold on its side***.

7.15 Extrude the specimen by orienting the mold so that the ram pushes on the bottom face (base plate face) of the specimen. If any specimen is deformed or damaged during extrusion, the entire set of specimens at that CRA binder content shall be discarded and a new set prepared.

7.16 Immediately upon extrusion, measure and record the height of the specimen to the nearest 0.001 inch and determine and record its weight in air to the nearest 0.1 gram. Compacted specimens shall be 2.500 $\pm$ 0.200 inches in height. If this criteria is not met for the specimens at each CRA binder content, the entire set of specimens at that CRA binder content shall be discarded and a new set prepared after necessary adjustments in the weight of aggregate have been made using Equation 2 (see Note 2 in Table 1).

7.17 Repeat the procedures in Subsections 7.4 through 7.16 for the required specimens.

8. BULK SPECIFIC GRAVITY/BULK DENSITY OF SPECIMENS

8.1 Determine the bulk specific gravity and bulk density of the three compacted AR-AC specimens at each CRA binder content in accordance with Method A of ARIZ 415, except the paraffin method shall not be used. The determination of the “Weight in Water” and “S.S.D. Weight" of each specimen will be completed before the next specimen is submerged for its "Weight in Water" determination.

Note 13: Specimens fabricated in the laboratory that have not been exposed to moisture do not require drying after extrusion from the molds. The specimen weight in air obtained in Subsection 8.1 is its dry weight.

8.2 For each CRA binder content, the densities of individual compacted specimens shall not differ by more than 2.0 pcf. If this density requirement is not met, the entire set of specimens at that CRA binder content shall be discarded and a new set of specimens prepared.

8.3 For each set of three specimens, determine the average bulk specific gravity (G_{mb}), and using that value calculate the average bulk density (G_{mb} multiplied by 62.3 lb./cu. ft.).

9. MARSHALL STABILITY AND FLOW DETERMINATION

9.1 Specimens shall be tested for Marshall Stability and Flow utilizing the apparatus specified in ARIZ 410.

Note 14: Marshall Stability and Flow values are determined and recorded for information only.

9.2 For each specimen, determine the uncorrected stability, the stability (corrected for height), and the flow according to ARIZ 410, Subsections 4.6 through 4.11. In addition, determine the average stability (corrected for height) and average flow for each set of specimens prepared at each CRA binder content.

Note 15: Flow values may be high compared to conventional asphaltic concrete mixtures.

10. MAXIMUM THEORETICAL SPECIFIC GRAVITY (RICE TEST)

10.1 The maximum theoretical specific gravity of the mixture shall be determined in accordance with ARIZ 806 with the following modifications:

10.1.1 Prepare the AR-AC specimens including mineral admixture according to the procedures described in Section 5 and Subsections 7.2 through 7.5 using 6.0% or 6.5% CRA by total mix weight. A liquid anti-stripping agent is not used.

10.1.2 Immediately after mixing, the material shall be thoroughly blended and spread according to the procedures described in ARIZ 416. The circular mass shall be cut into 6 equal pie-shaped segments. Take opposite segments for each individual test sample and use up the entire batch.

10.1.3 Each individual test sample shall be spread in a large pan at nominal single-stone thickness. Avoid stacking particles as feasible. The test samples shall be oven-cured for 2 hours ± 10 minutes at 325 ± 5 °F.

10.1.4 After curing, each test sample shall be spread on a sheet of heavy paper or in a large flat bottom pan. Before the samples are completely cooled, separate the particles of the mixture, taking care not to fracture the mineral aggregate particles, so that the particles of the fine aggregate portion are not larger than ¼ inch. Allow the test samples to cool to room temperature.

10.1.5 Using Equation 6, calculate the effective specific gravity of the combined aggregate and mineral admixture (G_{se}).

Equation 6:

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

Where:
G_{se} = Effective specific gravity of the combined aggregate and mineral admixture.
P_b = CRA binder content at which the Rice test was performed (Rice P_b).
G_{mm} = Measured maximum theoretical specific gravity of the mix at Rice P_b.
G_b = Specific gravity of the CRA.

Example:
P_b = 6.0
G_{mm} = 2.547
G_b = 1.037

$$G_{se} = \frac{100 - 6.0}{\frac{100}{2.547} - \frac{6.0}{1.037}} = 2.808$$

10.1.6 Using Equation 7, calculate the maximum theoretical specific gravity (G_{mm}) for each CRA binder content.

Note16: G_{se} is considered constant regardless of the CRA binder content.

Equation 7:

$$G_{mm} = \frac{100}{\frac{P_{sa}}{G_{se}} + \frac{P_b}{G_b}}$$

Where:
G_{mm} = Calculated maximum theoretical specific gravity of the AR-AC at each CRA binder content P_b.
P_{sa} = Aggregate and mineral admixture content, percent by total weight of mix (100-P_b).
P_b = Percent CRA binder content, by total weight of mix, for each CRA binder content.

G_{se} = Effective specific gravity of the combined aggregate and mineral admixture.
G_b = Specific gravity of the CRA.

Example (for 7.5% CRA binder content) (See Note 4):

P_{sa} = 92.5
P_b = 7.5
G_{se} = 2.808
G_b = 1.037

$$G_{mm} = \frac{100}{\frac{92.5}{2.808} + \frac{7.5}{1.037}} = 2.489$$

11. DETERMINATION OF DESIGN PERCENT CRA BINDER CONTENT

11.1 The design percent CRA binder content is determined as follows in Subsections 11.2 through 11.3.

11.2 For each CRA binder content used, calculate effective voids (V_a), percent absorbed CRA (P_{ba}), and voids in mineral aggregate (VMA) using the following equations.

11.2.1 Using Equation 8, calculate the effective voids (V_a). The calculated G_{mm} values for the respective CRA binder contents are used to determine the corresponding effective voids content of the compacted Marshall specimens at each CRA binder content.

Equation 8:

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

Where:

V_a = Effective voids in the compacted mixture, percent of total volume.
G_{mm} = Calculated maximum theoretical specific gravity of the AC-AR at each CRA binder content P_b.
G_{mb} = Bulk specific gravity of compacted mixture specimens.

Example (for 7.5% CRA binder content) (See Note 4):

G_{mm} = 2.489
G_{mb} = 2.263

$$V_a = \frac{2.489 - 2.263}{2.489} \times 100 = 9.1$$

11.2.2 Using Equation 9, calculate the percent absorbed CRA (P_{ba}).

Note17: The percent absorbed CRA (P_{ba}) is the same for all CRA binder contents.

Equation 9: $$P_{ba} = \left(\frac{G_{se} - G_{sb}}{G_{sb} \times G_{se}} \right) \times G_b \times 100$$

Where:
- P_{ba} = Absorbed CRA, percent by total weight of mix.
- G_{se} = Effective specific gravity of the combined aggregate and mineral admixture.
- G_{sb} = Bulk oven dry specific gravity of the combined aggregate and mineral admixture.
- G_b = Specific gravity of the CRA.

Example:
G_{se} = 2.808
G_{sb} = 2.750
G_b = 1.037

$$P_{ba} = \frac{2.808 - 2.750}{2.750 \times 2.808} \times 1.037 \times 100 = 0.78$$

11.2.3 Using Equation 10, calculate voids in mineral aggregate (VMA) of the compacted Marshall specimens at each CRA binder content.

Equation 10: $$VMA = 100 - \left(\frac{G_{mb} \times P_{sa}}{G_{sb}} \right)$$

Where: VMA = Voids in the mineral aggregate, percent of bulk volume.

G_{mb} = Bulk specific gravity of compacted mixture specimens.

P_{sa} = Aggregate and mineral admixture content, percent by total weight of mix (100-P_b).

G_{sb} = Bulk oven dry specific gravity of the combined aggregate and mineral admixture.

Example (for 7.5% CRA binder content) (See Note 4):

G_{mb} = 2.263
P_{sa} = 92.5
G_{sb} = 2.750

$$VMA = 100 - \frac{2.263 \times 92.5}{2.750} = 23.9$$

11.3 If the specified value for effective voids (V_a) falls between the resultant V_a values determined for two of the CRA binder contents used, straight-line interpolation shall be used to calculate the bulk specific gravity (G_{mb}) at each 0.1% CRA binder content increment between the two corresponding measured values of G_{mb}. Using equations 7 and 8, determine the values for G_{mm} and V_a at each interpolated CRA binder content. Select the CRA binder content which results in V_a being as close as possible to the specified value.

11.3.1 Using equation 10, calculate VMA at the selected CRA binder content. Using straight-line interpolation, determine the values for stability and flow that correspond to the selected CRA binder content. (Stability and flow values are detemined for information only.) If the value for VMA is within the limits of the specifications, the selected CRA binder content shall be the design CRA binder content.

11.3.2 On separate graphs (using the same scale for percent CRA binder for each graph), plot the values for bulk specific gravity, effective voids, VMA, stability, and flow for each set of three specimens and at the design CRA binder content versus the percent CRA binder. Draw a smooth “best fit” curve based on the plotted points, as shown in Figure 4. The graphs in Figure 4 are for illustrative purposes only. Straight-line interpolation, as specified in Subsections 11.3 and 11.3.1, is used for mix design calculations. (Values for stability and flow are plotted for information only.)

11.3.3 If it is not possible to obtain specification compliance within the range of CRA binder contents used, a determination must be made to either redesign the mix (different aggregate gradation and/or source) or prepare additional specimens at other CRA binder contents for testing and volumetric analyses.

11.4 Using Equation 11, calculate the percent effective CRA binder content (P_{be}) at each percent CRA binder content, including the design percent CRA binder content.

Equation 11:

$$P_{be} = P_b - \left(\frac{P_{ba} \text{ x } P_{sa}}{100} \right)$$

Where:

P_{be} = Percent effective CRA binder content of the mixture (free binder not absorbed).

P_b = CRA binder content, percent by total weight of mix.

P_{ba} = Absorbed CRA, percent by total weight of mix.

P_{sa} = Aggregate and mineral admixture content, percent by total weight of mix (100-P_b).

Example (for 9.3% CRA design binder content):

P_b = 9.3
P_{ba} = 0.78
P_{sa} = 90.7

$$P_{be} = 9.3 - \frac{0.78 \text{ x } 90.7}{100} = 8.59$$

12. MIX DESIGN GRADATION TARGET VALUES

12.1 The target values for the aggregate composite without mineral admixture, and the aggregate-mineral admixture blend composite, for the AR-AC mixture shall be expressed as percent passing particular sieve sizes as required by the specifications for the project. An example mix design composite, with and without mineral admixture, is shown in Figure 1.

13. REPORT

13.1 Report the test results and data obtained on the appropriate form. Liberal use of the remarks area to clarify and/or emphasize any element of the design is strongly recommended. Information required in the mix design report includes the items listed below:

13.1.1 Name and address of the testing organization and the signature and seal of the mix design engineer responsible for the mix design.

13.1.2 Aggregate:

- Source and identification
- Individual stockpile or bin gradations
- Aggregate blend proportions and composite gradation, with and without mineral admixture
- Fine and coarse aggregate specific gravities (Bulk Oven Dry, SSD, Apparent) and absorption
- Combined aggregate specific gravities (Bulk Oven Dry, SSD, Apparent)
- Combined aggregate absorption
- Aggregate quality
    - LA Abrasion
    - Sand Equivalent
    - Fractured Coarse Aggregate Particles (percentage with one fractured face and percentage with two fractured faces)
    - Uncompacted Void Content
    - Carbonates (when applicable)

13.1.3 Mineral Admixture:

- Type and source
- Percentage used
- Specific gravity

13.1.4 Combined Mineral Aggregate and Mineral Admixture

- Combined specific gravities [Bulk Oven Dry (G_{sb}), SSD, Apparent] and absorption of the combined aggregate and mineral admixture
- Effective specific gravity of the combined aggregate and mineral admixture (G_{se})

13.1.5 CRA Binder Design (from supplier), including:

- Source and grade of base asphalt cement
- Source and type of crumb rubber
- Crumb rubber gradation
- Proportions of asphalt cement and crumb rubber
    - Percentage of crumb rubber, by weight of asphalt cement
    - Percentages of crumb rubber and asphalt cement, by weight of total binder
- CRA binder properties, in compliance with Section 1009 of the ADOT Specifications
- CRA binder specific gravity (G_b) (at 77 °F)
- Asphalt cement specific gravity (at 77 °F)

13.1.6 Maximum theoretical specific gravity (G_{mm}) and density (pcf) at the CRA binder content at which the Rice test was performed (Rice P_b)

13.1.7 Mixture Compaction Trials:

- Percent CRA binder content (P_b), by weight of the bituminous mixture
- Aggregate and mineral admixture content (P_{sa})
- Calculated maximum theoretical specific gravity (G_{mm}) and density (pcf)
- Bulk specific gravity (G_{mb}) and bulk density (pcf) of Marshall specimens
- Percent effective voids (V_a)
- Percent voids in mineral aggregate (VMA)
- Percent absorbed CRA (P_{ba})
- Percent effective CRA binder content (P_{be})
- Marshall stability (nearest 10 pounds) (recorded for information only)
- Marshall flow (0.01 inch) (recorded for information only)

13.1.8 Plots of the following properties versus percent CRA binder content (See examples in Figure 4.):

- Percent effective voids (V_a)
- Percent voids in mineral aggregate (VMA)
- Bulk specific gravity (G_{mb})
- Marshall stability (for information only)
- Marshall flow (for information only)

13.1.9 Mixture Properties at Design Percent CRA Binder Content:

- Percent CRA binder content (P_b), by weight of the bituminous mixture
- Aggregate and mineral admixture content (P_{sa})
- Calculated maximum theoretical specific gravity (G_{mm}) and density (pcf)
- Bulk specific gravity (G_{mb}) and bulk density (pcf) of Marshall specimens
- Percent effective voids (V_a)
- Percent voids in mineral aggregate (VMA)
- Percent absorbed CRA (P_{ba})
- Percent effective CRA binder content (P_{be})
- Marshall stability (nearest 10 pounds) (recorded for information only)
- Marshall flow (0.01 inch) (recorded for information only)

13.1.10 Mix Design Summary. The mix design summary shall contain the information shown in Figure 5. [Pages 1 and 2 of an example Mix Design Summary for an Asphaltic Concrete (Asphalt-Rubber) Marshall Mix Design.]

Example Mix Design Composite
(With and Without Mineral Admixture)

Material	3/16" Washed Crusher Fines	1/4" Washed Crusher Fines	3/8" Aggregate	1/2" Aggregate	Composite		Specifications ADOT 415 [Asphaltic Concrete (Asphalt-Rubber)]	
Percent used in composite	15	9	30	46	Without Admix	With Admix*	Without Admix	With Admix
Sieve	Gradation – Percent Passing							
3/4"	100.0	100.0	100.0	100.0	100	100	100	100
1/2"	100.0	100.0	100.0	92.1	96	96	80 - 100	80 - 100
3/8"	100.0	100.0	95.4	48.1	75	75	65 - 80	65 - 80
1/4"	100.0	100.0	73.4	7.6	50	50		
#4	99.8	92.2	41.1	4.4	38	39	28 - 42	29 - 43
#8	75.0	50.9	6.6	2.9	19	20	14 - 22	15 - 23
#10	67.3	43.6	5.5	2.6	17	18		
#16	46.5	26.3	3.8	2.3	12	13		
#30	26.5	14.1	3.0	2.1	7	8		
#40	18.3	9.8	2.8	2.0	5	6		
#50	12.9	7.0	2.5	1.9	4	5		
#100	6.7	3.9	2.2	1.7	3	4		
#200	4.0	2.5	1.9	1.4	2.0	3.0	0 - 2.5	0 – 3.5

* 1.0 percent admixture, by weight of dry mineral aggregate, is used.

FIGURE 1

Example Weigh Up Sheet #1

MATERIAL	SIEVE	INDIV. % RET.	ACCUM. % RET.	FRACTURED COARSE AGGREGATE PARTICLES [Plus #4] (500 grams)	PERCENT CARBONATES [Plus #4] (300 grams)	COARSE AGGREGATE SPECIFIC GRAVITY/ ABSORPTION [Plus #4] (4000 grams)	FINE AGGGREGATE SPECIFIC GRAVITY/ ABSORPTION [Minus #4] (1200 grams)	SAND EQUIVALENT [Minus #4] (600 grams)	UNCOMPACTED VOID CONTENT [Minus #8] (500 grams)	ABRASION [Type C] (5000 grams)
				ACCUMULATIVE WEIGHT (grams)						
3/16" Washed Crusher Fines	#4	0.030	0.030	---	---	2	---	---	---	6
	#8	3.720	3.750	---	---	---	119	59	---	---
	- #8	11.250	15.000	---	---	---	477	239	294	---
1/4" Washed Crushed Fines	#4	0.702	15.702	6	4	47	---	---	---	154
	#8	3.717	19.419	---	---	---	596	298	---	---
	- #8	4.581	24.000	---	---	---	742	371	413	---
3/8" Aggregate	3/8"	1.380	25.380	17	10	135	---	---	---	---
	1/4"	6.600	31.980	70	42	559	---	---	---	808
	#4	9.690	41.670	148	89	1180	---	---	---	2845
	#8	10.350	52.020	---	---	---	1072	536	---	---
	- #8	1.980	54.000	---	---	---	1135	568	465	---
1/2" Aggregate	1/2"	3.634	57.634	177	106	1413	---	---	---	---
	3/8"	20.240	77.874	339	203	2711	---	---	---	---
	1/4"	18.630	96.504	488	293	3906	---	---	---	4691
	#4	1.472	97.976	500	300	4000	---	---	---	5000
	#8	0.690	98.666	---	---	---	1157	579	---	---
	- #8	1.334	100.00	---	---	---	1200	600	500	---

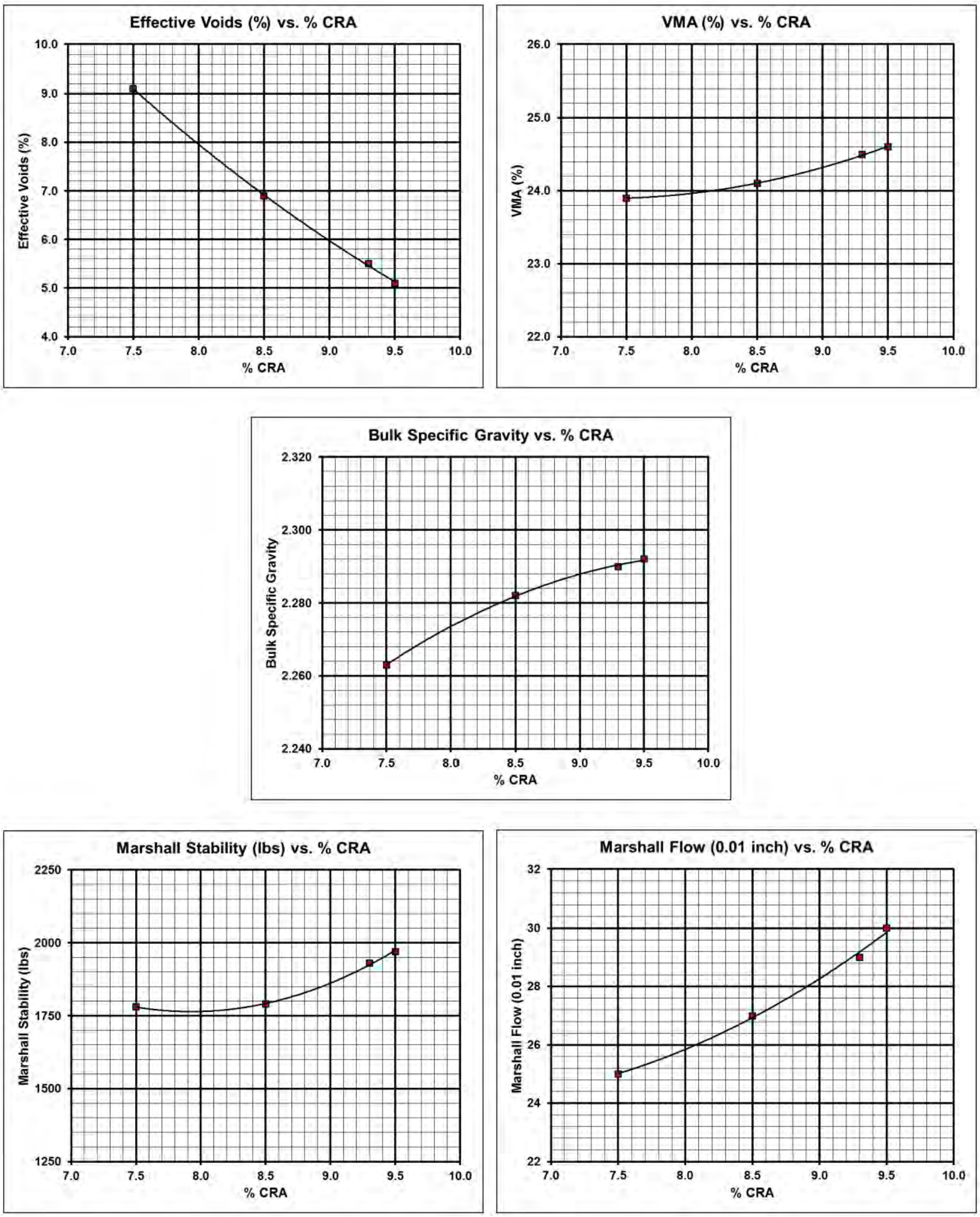
FIGURE 2

Example Weigh Up Sheet #2

MATERIAL	SIEVE	INDIVIDUAL PERCENT RETAINED	ACCUMULATIVE PERCENT RETAINED	RICE (3000 grams)	MARSHALL (3000 grams)	MINUS NO. 8 MAKE-UP MATERIAL (500 grams)
				ACCUMULATIVE WEIGHT (grams)		
3/16" Washed Crusher Fines	#4	0.030	0.030	1	1	---
	#8	3.720	3.750	113	113	---
	- #8	11.250	15.000	450	450	294
1/4" Washed Crusher Fines	#4	0.702	15.702	471	471	---
	#8	3.717	19.419	583	583	---
	- #8	4.581	24.000	720	720	413
3/8" Aggregate	3/8"	1.380	25.380	761	761	---
	1/4"	6.600	31.980	959	959	---
	#4	9.690	41.670	1250	1250	---
	#8	10.350	52.020	1561	1561	---
	- #8	1.980	54.000	1620	1620	465
1/2" Aggregate	1/2"	3.634	57.634	1729	1729	---
	3/8"	20.240	77.874	2336	2336	---
	1/4"	18.630	96.504	2895	2895	---
	#4	1.472	97.976	2939	2939	---
	#8	0.690	98.666	2960	2960	---
	- #8	1.334	100.000	3000	3000	500
Weight of Mineral Admixture (Hydrated Lime) [1.0%, by weight of Dry Mineral Aggregate]				30	30	---
Total weight of Mineral Aggregate and Mineral Admixture				3030	3030	---

FIGURE 3

Example Plots of Effective Voids, VMA, Bulk Specific Gravity, Marshall Stability, and Marshall Flow versus Percent CRA Binder Content (Marshall Stability and Marshall Flow are plotted for information only.)



The above graphs are for illustrative purposes only. Straight-line interpolation, as specified in Subsections 11.3 and 11.3.1, is used for mix design calculations.

FIGURE 4

Asphaltic Concrete (Asphalt-Rubber) Marshall Mix Design
Example Mix Design Summary (Page 1 of 2)

Date: February 22, 2013

Contractor: Best Paving Contractors, Inc.	
ADOT Project Number: STP-777-Z(777)A	
ADOT TRACS Number: H777701C	
Project Name: Uptown - Downtown	

Mix Designation: ADOT 415 [Asphaltic Concrete (Asphalt-Rubber)]	
Mix Design Laboratory: XYZ Testing Laboratories	
Mix Design Engineer: Frank Dogood	
Grade of Asphalt-Rubber Binder: CRA Type 2	

COMPOSITE GRADATION:

Mineral Aggregate	Percent Used
3/16" Washed Crusher Fines	15
1/4" Washed Crusher Fines	9
3/8" Aggregate	30
1/2" Aggregate	46
Mineral Admixture	
Hydrated Lime	1.0

Sieve Size	Percent Passing w/o Admix	Percent Passing w/ Admix	Specifications	
			Without Admix	With Admix
3/4"	100	100	100	100
1/2"	96	96	80 - 100	80 - 100
3/8"	75	75	65 - 80	65 - 80
1/4"	50	50		
#4	38	39	28 - 42	29 - 43
#8	19	20	14 - 22	15 - 23
#10	17	18		
#16	12	13		
#30	7	8		
#40	5	6		
#50	4	5		
#100	3	4		
#200	2.0	3.0	0 – 2.5	0 – 3.5

AGGREGATE PROPERTIES:

Test Characteristic	Fine	Coarse	Combined	Spec.
Bulk O.D. Specific Gravity	2.732	2.772	2.757	2.350 – 2.850
SSD Specific Gravity	2.798	2.819	2.811	-----
Apparent Specific Gravity	2.925	2.907	2.914	-----
Absorption	2.42	1.68	1.96	0 – 2.5%
Sand Equivalent	97			Min. 55
Uncompacted Void Content	47.8			Min. 45.0%
Carbonates	2			Max. 20%
Fractured Coarse Aggregate Particles				
At least one fractured face	99			Min. 92%
At least two fractured faces	97			Min. 85%
Abrasion	(Type C)			
100 Rev., % Loss	3			9% Max.
500 Rev. ,%Loss	14			40% Max.

DESIGN DATA:

% CRA	7.5	8.5	**9.3**	9.5	Spec.
Bulk Specific Gravity	2.263	2.282	**2.290**	2.292	
Bulk Density (lb./cu. ft)	141.0	142.2	**142.7**	142.8	
Stability (lb.)	1780	1790	**1930**	1970	
Flow (0.01 inch)	25	27	**29**	30	
Effective Voids (%)	9.1	6.9	**5.5**	5.1	5.5 ± 0.5
VMA (%)	23.9	24.1	**24.5**	24.6	19.0 Min.
Effective CRA, Total Mix (%)	6.78	7.79	**8.59**	8.79	
Absorbed CRA (%)	0.78				0 – 1.0
Max. Theoretical Specific Gravity at 9.3% CRA = 2.423					
Max. Theoretical Density at 9.3% CRA = 151.0 lb/cu. ft.					

RECOMMENDED CRA BINDER CONTENT: (By weight of total mix)	**9.3%**

COMBINED AGGREGATE AND MINERAL ADMIXTURE PROPERTIES:

Bulk O.D.Specific Gravity	2.750
SSD Specific Gravity	2.803
Apparent Specific Gravity	2.905
Water Absorption	1.94
Effective Specific Gravity	2.808

ADDITIONAL DATA / INFORMATION:

Source of Mineral Aggregate: Excellent Aggregate Materials, Inc.
Source of Mineral Admixture: Superior Lime Company, Inc.
Mineral Admixture Type/Specific Gravity: Hydrated Lime/2.20

CRA BINDER DESIGN: (SEE PAGE 2)

REMARKS:

FIGURE 5 (Continued on Next Page)

Asphaltic Concrete (Asphalt-Rubber) Marshall Mix Design
Example Mix Design Summary (Page 2 of 2)

CRA BINDER DESIGN		
Source of Base Asphalt Cement: Supreme Asphalt Suppliers, Inc.		
Source of Crumb Rubber: Rubber Suppliers, Inc.		
Grade of Base Asphalt Cement: PG 58-22		
Type of Crumb Rubber: Type B		
Grade of Asphalt-Rubber Binder: CRA Type 2		
Specific Gravity of Base Asphalt Cement: 1.009 (at 77 °F)		
Specific Gravity of CRA Binder: 1.037 (at 77 °F)		
Crumb Rubber (by weight of asphalt cement): 20.5% (Minimum 20% required)		
Proportions of Asphalt Cement and Crumb Rubber (by weight of total binder): 83.0% Asphalt Cement 17.0% Crumb Rubber		
CRA Binder Properties (ADOT Specifications Section 1009):		
Property	Test Result	Requirements (CRA Type 2)
Rotational Viscosity: 177 °C (350 °F); (Rion Model VT-04, No. 1 Rotor); Pascal·seconds	2.1	1.5 – 4.0
Penetration: 4 °C (39.2 °F), 200 g, 60 sec. (ASTM D 5); 0.1 mm	26	15 Minimum
Softening Point: (AASHTO T 53); °C	61	54 Minimum
Resilience: 25 °C (77 °F) (ASTM D 5329); %	47	20 Minimum
Crumb Rubber Gradation (Arizona Test Method 714):		
Sieve Size	Percent Passing	Requirements (Type B)
No. 10	100	100
No. 16	90	65 – 100
No. 30	30	20 – 100
No. 50	7	0 – 45
No. 200	0.3	0 - 5

FIGURE 5 (Continued from Previous Page)

ARIZ 833
February 22, 2013
(52 Pages)

MARSHALL MIX DESIGN METHOD FOR ASPHALTIC CONCRETE WITH RECLAIMED ASPHALT PAVEMENT (RAP)

(An Arizona Method)

1. SCOPE

1.1 This method is used to design Asphaltic Concrete mixes with Reclaimed Asphalt Pavement (RAP) using 4-inch diameter Marshall apparatus.

1.2 This test method involves hazardous material, operations, and equipment. This test method does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1.3 See Appendix A1 of the Materials Testing Manual for information regarding the procedure to be used for rounding numbers to the required degree of accuracy.

1.4 A listing of subsequent Sections and Figures in this procedure is given below:

Section or Figure #	Title	Page #
Section 2	Test Methods and Apparatus	2
Section 3	Materials	3
Section 4	Determination of Composite Gradation	5
Section 5	Preparing Aggregate/RAP/Mineral Admixture Samples for Mix Design Testing	7
Section 6	Virgin Aggregate and RAP Aggregate Specific Gravities and Absorption	12
Section 7	Asphalt Binder Selection	20
Section 8	Laboratory Mixing and Compaction Temperatures	23
Section 9	Preparation of Specimens for Bulk Specific Gravity/Bulk Density and Marshall Stability/Flow Determination	25
Section 10	Bulk Specific Gravity/Bulk Density of Specimens	29
Section 11	Marshall Stability and Flow Determination	30
Section 12	Maximum Theoretical Specific Gravity (Rice Test)	30
Section 13	Determination of Design Asphalt Binder Content	32
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2. TEST METHODS AND APPARATUS

2.1 This test method is used in conjunction with the test methods and standards listed below. Requirements for the frequency of equipment calibration and verification are found in Appendix A3 of the Materials Testing Manual. The required apparatus is shown in the individual test methods and standards listed below, as appropriate.

2.1.1 Arizona Test Methods:

- ARIZ 201 Sieving of Coarse and Fine Graded Soils and Aggregates
- ARIZ 205 Composite Grading
- ARIZ 210 Specific Gravity and Absorption of Coarse Aggregate
- ARIZ 211 Specific Gravity and Absorption of Fine Aggregate
- ARIZ 212 Percentage of Fractured Coarse Aggregate Particles
- ARIZ 238 Percent Carbonates in Aggregate
- ARIZ 240 Sieve Analysis and Separation of Salvaged AC Pavement Particles for Recycled Asphaltic Concrete
- ARIZ 247 Particle Shape and Texture of Fine Aggregate Using Uncompacted Void Content
- ARIZ 248 Alternate Procedures for Sieving of Coarse and Fine Graded Soils and Aggregates
- ARIZ 251 Combined Coarse and Fine Aggregate Specific Gravity and Absorption
- ARIZ 406 Moisture Content of Bituminous Mixtures
- ARIZ 410 Compaction and Testing of Bituminous Mixtures Utilizing Four Inch Marshall Apparatus
- ARIZ 415 Bulk Specific Gravity and Bulk Density of Compacted Bituminous Mixtures
- ARIZ 416 Preparing and Splitting Field Samples of Bituminous Mixtures for Testing

- ARIZ 417 Maximum Theoretical Specific Gravity of Field Produced Bituminous Mixtures
- ARIZ 802 Effect of Water on Strength of Compacted Treated and Untreated Bituminous Mixtures (Immersion Compression Test)
- ARIZ 806 Maximum Theoretical Specific Gravity of Laboratory Prepared Bituminous Mixtures (Rice Test)

2.1.2 AASHTO Standards:

- AASHTO M 320 Standard Specification for Performance-Graded Asphalt Binder
- AASHTO R 29 Grading or Verifying the Performance Grade of an Asphalt Binder
- AASHTO T 96 Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
- AASHTO T 164 Quantitative Extraction of Asphalt Binder from Hot-Mix Asphalt (HMA) – Method A
- AASHTO T 170 Recovery of Asphalt from Solution by Abson Method
- AASHTO T 176 Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
- AASHTO T 228 Specific Gravity of Semi-Solid Bituminous Materials

Note 1: Testing by AASHTO T 228 shall be performed at 77 °F.

- AASHTO T 248 Reducing Samples of Aggregate to Testing Size
- AASHTO T 316 Viscosity Determination of Asphalt Binder Using Rotational Viscometer

2.1.3 ASTM Standards:

- ASTM D 2493 Standard Viscosity-Temperature Chart for Asphalts
- ASTM D 5404 Standard Practice of Recovery of Asphalt from Solution Using the Rotary Evaporator

3. MATERIALS

3.1 Mineral Aggregate - The mineral aggregate used in the design shall be produced material from the source(s) for the project. Mineral aggregate shall consist of a combination of virgin aggregate and aggregate from RAP (RAP aggregate). When the terms “mineral aggregate” or “aggregate” are used without being further described as “virgin” or “RAP”, the intended meaning is the total aggregate material used in the mixture.

3.1.1 RAP aggregate used for mix design purposes shall be extracted aggregate from AASHTO T 164 (Method A), except RAP aggregate used for Abrasion testing may be obtained using an ignition furnace.

3.1.2 The composited gradation of the virgin aggregate and RAP aggregate, and the composited gradation of the virgin aggregate-RAP aggregate-mineral admixture blend, shall comply with the grading limits of the specifications.

3.1.3 The composited virgin mineral aggregate shall conform to the requirements of the specifications for Sand Equivalent (AASHTO T 176), Combined Bulk Oven Dry Specific Gravity (ARIZ 251), Combined Water Absorption (ARIZ 251), and when applicable, Uncompacted Void Content (ARIZ 247).

3.1.4 The composited virgin aggregate and RAP aggregate shall conform to the requirements of the specifications for Fractured Coarse Aggregate Particles (ARIZ 212) and when applicable, Percent Carbonates (ARIZ 238).

3.1.5 Virgin mineral aggregate and RAP aggregate from each source shall be tested separately for compliance to the project requirements for Abrasion (AASHTO T 96). If multiple RAP stockpiles are utilized, and if the stockpiles are from different sources, an abrasion test will be necessary for each source. If the RAP is obtained from one source and is fractionated, one abrasion test will suffice.

3.2 Reclaimed Asphalt Pavement (RAP) - RAP consists of salvaged, milled, pulverized, broken, or crushed asphalt pavement. RAP contains “RAP aggregate” and bituminous materials hereinafter referred to as “RAP Binder”. The gradation of the RAP material shall conform to the requirements of the specifications.

3.3 Bituminous Material - The bituminous material used in the design shall be the total asphalt binder which is to be used in the production of the asphaltic concrete. Bituminous material shall consist of a combination of virgin asphalt binder and asphalt binder from RAP (RAP binder). When the terms “bituminous material” or “asphalt binder” or “binder” are used without being further described as “virgin” or “RAP”, the intended meaning is the total bituminous material used in the mixture.

3.3.1 If ≤15% RAP binder is being used, the virgin binder must conform to the requirements of Section 1005 of the specifications for the specific grade of binder shown in the Special Provisions. The specific gravity of the virgin asphalt binder used in the asphaltic concrete shall be determined in accordance with AASHTO T 228 (at 77 °F). (See Section 7.)

3.3.2 If >15% RAP binder is being used, the blended RAP binder and virgin binder must conform to the requirements of Section 1005 of the specifications for the specific grade of binder shown in the Special Provisions. The specific gravity of the virgin asphalt binder, the specific gravity of the RAP binder from each RAP stockpile, and the specific gravity of the blended RAP binder and virgin binder shall be determined in accordance with AASHTO T 228 (at 77 °F). (See Section 7.) As an alternate to determining the specific gravity of the recovered RAP binder from each RAP stockpile, the specific gravity of proportionally blended recovered RAP binder may be determined. (See Note 9.)

3.4 Mineral Admixture - Mineral admixture is required. The mineral admixture used in the design shall be the same type of material which is to be used in production of the asphaltic concrete. The mineral admixture shall conform to the requirements of the specifications.

3.5 Batch Plants - Mix designs developed for asphaltic concrete which is to be produced in a batch plant shall be prepared in accordance with this procedure, modified as follows:

3.5.1 Virgin aggregate samples will be obtained from the hot bins for all testing except Sand Equivalent. Testing for Sand Equivalent will be performed on virgin aggregate stockpile samples proportioned and composited to meet Composite #2 without admixture. Any method may be used to combine the virgin aggregate stockpile samples for Sand Equivalent testing as long as the resultant gradation is representative of the composite gradation without admixture shown in Composite #2.

3.5.2 The mix design shall provide component percentages and composite gradations for both stockpile and hot bin materials.

4. DETERMINATION OF COMPOSITE GRADATION

4.1 The gradation of the aggregate from each individual component stockpile, bin, or RAP aggregate, shall be determined in accordance with ARIZ 248 using washed sieve analysis Alternate #3, Alternate #4, or Alternate #5. The RAP aggregate gradation shall be determined using the aggregate from solvent extraction testing of the RAP. For Alternate #5, washing of the coarse aggregate may be performed on the composite plus No. 4 material and applied to the composite percent pass the minus No. 200 determined from the unwashed coarse sieving and washed fine sieving of the individual stockpiles.

4.2 The composite gradation of the virgin aggregate and RAP aggregate blend is determined using desired percentages of each component based on washed sieve analysis. Mix designs may be developed based on bin or stockpile material, as appropriate for the respective mix production facility to be used.

4.3 The virgin aggregate and RAP aggregate blend composite shall be determined in accordance with ARIZ 205, paragraph 2(e).

4.4 The virgin aggregate-RAP aggregate-mineral admixture blend composite is determined by adjusting the virgin aggregate and RAP aggregate blend composite (percent passing) for mineral admixture by performing the calculation in Equation 1 for each sieve:

Equation 1:

$$\begin{bmatrix}\text{\% passing} \\ \text{each sieve} \\ \text{(Adjusted for} \\ \text{Mineral} \\ \text{Admixture)}\end{bmatrix} = \frac{\begin{pmatrix}\text{\% passing each} \\ \text{sieve in the} \\ \text{virgin aggregate} \\ \text{and RAP aggregate} \\ \text{blend composite}\end{pmatrix} + \begin{pmatrix}\text{\% Mineral} \\ \text{Admixture}\end{pmatrix}}{(100) + (\text{\% Mineral Admixture})} \text{ x } 100$$

4.5 The composite gradations of the components and the percentage of each will be included in the design report for each of the composite types listed below.

4.5.1 Composite #1 - Virgin Aggregate and RAP Aggregate (with and without mineral admixture).

4.5.2 Composite #2 - Virgin Aggregate (with and without mineral admixture)

4.5.3 Composite #3 - Virgin Aggregate and Dry Screened RAP (without mineral admixture)

5. PREPARING AGGREGATE/RAP/MINERAL ADMIXTURE SAMPLES FOR MIX DESIGN TESTING

5.1 Preparation of Mineral Aggregate:

5.1.1 Dry the mineral aggregate from each individual stockpile at a temperature not exceeding any temperature restrictions specified in subsequent test procedures. Drying shall be performed until no further weight loss is obtained from continued drying.

5.1.2 Based on the virgin mineral aggregate stockpile or bin gradations and composite percentages, virgin mineral aggregate material which is retained on the individual No. 8 and larger sieve sizes, and the minus No. 8 material, is used to prepare samples for mix design testing.

5.1.3 Based on the RAP aggregate gradation(s) and composite percentage(s), RAP aggregate material which is retained on the individual No. 8 and larger sieve sizes, and the minus No. 8 material, is used to prepare samples for mix design testing.

5.2 Preparation of Reclaimed Asphalt Pavement (RAP):

5.2.1 Drying/Processing of RAP:

5.2.1.1 Based on the amount of RAP used in the composite gradation, determine the minimum weight of RAP from each stockpile needed for mix design, then increase it by 100% to be sure enough is available for possible retesting.

5.2.1.2 Spread the material from each individual RAP stockpile to be used for mix design testing in separate pans at 1 to 1½ inches in depth and dry in an oven at 140 ± 5 °F such that no further weight loss is obtained from continued drying at 140 ± 5 °F. Allow the material to cool. Split or quarter samples of RAP material from each stockpile, in accordance with AASHTO T 248, as necessary to perform the remainder of the testing and batching required in Section 5.

5.2.1.3 Determine the RAP binder content of material from each RAP stockpile, by weight of RAP, in accordance with AASHTO T 164 – Method A (Centrifuge Extraction) and the gradation of the extracted RAP aggregate in accordance with ARIZ 248. Determine the moisture content in accordance with ARIZ 406.

Note 2: For mixes utilizing >15% RAP binder, the extract from the solvent extraction is saved for testing as specified in Subsection 7.2. Specific time frames related to binder recovery must be followed. (See Subsection 7.4.1.)

5.2.1.4 The binder content of RAP material from each individual stockpile is recorded as "P_{br}" ("P_{br1}" and "P_{br2}", if two RAP stockpiles are used).

5.2.2 Dry Gradation of RAP (into individual sizes for No. 8 and larger sieves, and minus No. 8 material):

5.2.2.1 Determine the appropriate size test sample of each individual RAP stockpile as shown in Table 1.

Table 1

Maximum Size of Particle	**Minimum Weight of Sample, grams (lbs)**
1¼"	10000 (22)
3/4"	5000 (11)
1/2"	2000 (4.4)
3/8"	1000 (2.2)

5.2.2.2 Dry sieve each test sample in accordance with ARIZ 240, but utilizing the No. 8 sieve as the smallest sieve. Compute the unwashed gradation in accordance with ARIZ 248, Alternate #2. This gradation is used only for batching test specimens for Batch Sheet #3. (See Subsection 5.3.3.)

5.2.3 Screening of dry RAP into individual sizes for use in mix design batching:

5.2.3.1 Screen the RAP material from the individual stockpiles and separate into individual sizes for No. 8 and larger sieves, and minus No. 8 material. The RAP shall be screened for 5 minutes ± 15 seconds per ARIZ 240 to prevent excessive breakdown of the RAP agglomerations. The screened RAP will be used in Batch Sheet #3.

5.3 Batching of Test Samples: Multiple batch sheets, as described below, will be necessary due to the use of RAP. Batch Sheet #1 is for samples which include virgin aggregate and RAP aggregate. Batch Sheet #2 is for samples where only the virgin aggregate is used. Batch Sheet #3 is for samples that include virgin aggregate, RAP, and mineral admixture; where the virgin aggregate and mineral admixture must be wet treated prior to incorporating the RAP. Each virgin mineral aggregate, RAP aggregate, and RAP component which has been screened into individual sizes for No. 8 and larger sieves, and minus No. 8 material, will be used in the batching process.

5.3.1 Batch Sheet #1:

5.3.1.1 This batch sheet will utilize the individual virgin aggregate gradations and the RAP aggregate gradation(s) determined from solvent extraction (except RAP aggregate used for abrasion testing may be obtained using an ignition furnace). The component proportions will be based on Composite #1.

5.3.1.2 Samples for Fractured Coarse Aggregate Particles, Percent Carbonates (if required), and Abrasion (each separate source of virgin aggregate and RAP aggregate) will be prepared using Batch Sheet #1.

5.3.1.3 Examples of Composite #1 and corresponding Batch Sheet #1 are shown in Figures 1 and 2, respectively.

5.3.2 Batch Sheet #2:

5.3.2.1 This batch sheet will utilize the individual virgin aggregate gradations. The individual virgin stockpile proportions will be based on Composite #2. The percentage of material from each virgin aggregate stockpile is adjusted, as shown in Equations 18 and 19 (prior to Figure 3), so that the sum of the virgin aggregate stockpile percentages equal 100 percent.

5.3.2.2 Samples for Coarse and Fine Aggregate Specific Gravity and Absorption, Sand Equivalent, and Uncompacted Void Content (when required) will be prepared using Batch Sheet #2. In addition, minus No. 8 virgin aggregate make-up material is prepared using Batch Sheet #2.

5.3.2.3 Examples of Composite #2 and corresponding Batch Sheet #2 are shown in Figures 3 and 4, respectively.

5.3.3 Batch Sheet #3:

5.3.3.1 This batch sheet will utilize the individual virgin aggregate gradations and the gradation of the dry screened RAP material from each stockpile. The individual component stockpile proportions will be based on Composite #3. The percent of RAP material from each stockpile is adjusted to account for the RAP binder contained in the RAP material, as shown in Section 18. Marshall, Maximum Theoretical Specific Gravity (Rice Test), and Immersion Compression (IMC) samples will be prepared using Batch Sheet #3. Also using Batch Sheet #3, samples of dry screened RAP material are prepared for performing the Rice Test for each individual RAP stockpile. (See Subsection 6.3.1.4.)

5.3.3.2 Examples of Composite #3 and corresponding Batch Sheet #3 are shown in Figures 5 and 6, respectively.

5.3.3.3 The virgin aggregate samples for the Marshall, Rice, and Immersion Compression (IMC) specimens are batched separately from the RAP. Add the required percentage of mineral admixture to the virgin aggregate samples, by dry weight of the total aggregate (virgin aggregate and RAP aggregate), and mix thoroughly. Add 3% water, by dry weight of virgin aggregate, to each batched virgin aggregate/mineral admixture sample and mix thoroughly to wet the mineral admixture and virgin aggregate surfaces.

5.3.3.3.1 After mixing, place the wet treated virgin aggregate in a suitable pan, form a shallow crater in the center of the aggregate, and place the RAP material from each stockpile in the crater (do not allow the RAP material to touch the pan).

5.3.3.4 Testing utilizing the prepared virgin aggregate-RAP-mineral admixture samples for Marshall, Rice, and Immersion Compression will be performed as specified in Sections 9-11, 12, and 14, respectively.

5.3.4 Table 2 summarizes the test samples required for each batch sheet.

Table 2

Sample Type	**Sample Size**	**Number of Samples**	**Batch Sheet #**
Fractured Coarse Aggregate Particles (ARIZ 212)	Required grams of Virgin Mineral Aggregate and RAP Aggregate as determined by test method [No mineral admixture]	1	1
Percent Carbonates (ARIZ 238) (When required)	300 grams of Virgin Mineral Aggregate and RAP Aggregate [No mineral admixture]	1	1
Abrasion (AASHTO T 96)	5000 grams of Virgin Mineral Aggregate as per test method for grading type [No mineral admixture]	1	1
Abrasion (AASHTO T 96)	5000 grams of RAP Aggregate as per test method for grading type [No mineral admixture]	1	1
Fine Aggregate Specific Gravity/Absorption (ARIZ 211)	1200 grams of Virgin Mineral Aggregate [No mineral admixture]	1	2

Table 2 (Continued)			
Coarse Aggregate Specific Gravity/Absorption (ARIZ 210)	Required grams of Virgin Mineral Aggregate as determined by the Nominal Maximum Aggregate Size [No mineral admixture]	1	2
Sand Equivalent (AASHTO T 176)	500 to 750 grams of Virgin Mineral Aggregate [No mineral admixture]	1	2
Uncompacted Void Content (ARIZ 247) (When required)	Minimum 500 grams of Virgin Mineral Aggregate [No mineral admixture]	1	2
Minus No. 8 Make-Up Material	An adequate amount (normally 500 grams) of Virgin Mineral Aggregate [No mineral admixture]	1	2
Maximum Theoretical Specific Gravity (Rice Test) (ARIZ 806, as modified in Section 12)	3000 grams of Virgin Mineral Aggregate and RAP Aggregate (See Note 3.) [Plus mineral admixture, by percent required by ARIZ 802 (as modified in Section 14)]	1 [Yields 3 test specimens]	3
Maximum Theoretical Specific Gravity (Rice Test) [ARIZ 417, as modified in Subsection 6.3.1.4]	3150 grams of Dry Screened RAP Material [No mineral admixture]	1 (for each RAP stockpile) [Yields 3 test specimens]	3
Marshall Density-Stability/Flow (ARIZ 415 and ARIZ 410, as modified in Sections 9 through 11)	3300 grams of Virgin Mineral Aggregate and RAP Aggregate (See Notes 3 and 4.) [Plus mineral admixture, by percent required by ARIZ 802 (as modified in Section 14)]	3 (See Note 5.) [Each sample yields 1 set of 3 Marshall Specimens]	3
Immersion Compression (ARIZ 802, as modified in Section 14)	3400 grams of Virgin Mineral Aggregate and RAP Aggregate (See Notes 3 and 4.) [Plus required percent of mineral admixture]	3 [Each sample yields 1 set of 2 IMC Specimens]	3

Table 2 (Continued)	
Note 3:	Samples are prepared with Virgin Mineral Aggregate and Dry Screened RAP material, however the amount shown for each sample is actually the amount of Virgin Mineral Aggregate and RAP Aggregate in the sample. Due to the asphalt binder in the RAP material, the required amount of RAP material necessary to provide the required samples of Virgin Mineral Aggregate and RAP Aggregate will be greater than that shown, as illustrated in Figure 6. The adjusted percent of RAP material from each stockpile to be used is determined as shown in Section 18.
Note 4:	Generally the weight of virgin aggregate and RAP shown will provide specimens of acceptable heights, but adjustments may be necessary in some cases. Use Equation 2 to adjust sample size as necessary to conform to specimen height requirements of 2.500 ± 0.200 inches for Marshall Density-Stability/Flow specimens and 4.000 ± 0.100 inches for IMC specimens.

Equation 2:

$$\left[\text{Adjusted Sample Size}\right] = \frac{\begin{pmatrix}\text{Combined Bulk O.D.} \\ \text{Agg. Specific Gravity}\end{pmatrix}}{2.650} \times \begin{pmatrix}\text{3300 grams (for Marshall} \\ \text{Density - Stability/Flow)} \\ \text{or 3400 grams (for} \\ \text{Immersion Compression)}\end{pmatrix}$$

Note 5: Requires one (1) sample for each asphalt binder content to be tested (minimum of 3 binder contents, with 3 Marshall specimens at each binder content).

6. VIRGIN AGGREGATE AND RAP AGGREGATE SPECIFIC GRAVITIES AND ABSORPTION

6.1 Determine the Bulk Oven Dry, S.S.D., Apparent Specific Gravities and Absorption for the virgin fine aggregate (minus No. 4) and the virgin coarse aggregate (plus No. 4) in accordance with ARIZ 211 and ARIZ 210, respectively.

6.2 Determine the combined bulk oven dry specific gravity of the virgin fine aggregate and the virgin coarse aggregate without mineral admixture and also the combined water absorption of the virgin fine aggregate and the virgin coarse aggregate without mineral admixture, in accordance with ARIZ 251. The composite of virgin aggregate materials is determined by Composite #2.

6.2.1 The combined virgin aggregate bulk oven dry specific gravity without mineral admixture and the combined virgin aggregate water absorption without mineral admixture are used to determine compliance with specification requirements.

6.2.2 The combined virgin aggregate water absorption without mineral admixture is recorded as "A_v" and used in Equations 4b, 4c, and 6.

6.3 Estimate the Bulk Oven Dry Specific Gravity of the RAP aggregate from each RAP stockpile as follows.

6.3.1 For each RAP stockpile, the following items are used in the calculations.

6.3.1.1 The estimated binder absorption of the RAP aggregate.

Note 6: The binder absorption of the RAP aggregate (P_{bar}) is normally estimated to be 0.50 percent. An exception is made when the binder content of the RAP material is less than 1.00 percent, in which case the binder absorption of the RAP aggregate is estimated to be one-half of the binder content of the RAP material.

6.3.1.2 The tested specific gravity of the recovered RAP binder (when >15% RAP binder is used) or an estimated specific gravity of 1.050 for the RAP binder (when ≤15% RAP binder is used).

6.3.1.3 The binder content of the RAP material.

6.3.1.4 The maximum theoretical specific gravity and the effective specific gravity of the RAP aggregate determined in accordance with ARIZ 417, modified as follows:

6.3.1.4.1 From each RAP stockpile, weigh up a 3150 gram sample of dry screened material for individual No. 8 and larger sieves, and minus No. 8 material per the “As-Received” gradation. For an example, see the right side of Figure 6. Each 3000 gram sample is split into three individual approximate 1000 gram samples. Alternatively, individual 1000 gram samples may be weighed up separately.

6.3.1.4.2 Spread each sample in a large pan at nominal single stone thickness.

6.3.1.4.3 Place the sample in an oven at 230 ± 5 °F for 30 ± 5 minutes.

6.3.1.4.4 Immediately upon removal from the oven, break up fine particle agglomerations so that they are not larger than 1/4-inch, taking care not to fracture the aggregate particles.

6.3.1.4.5 Care must be taken not to lose minus No. 200 material while removing the sample from the flask following the evacuation of air from the sample. A recovery container must be provided to capture the water and minus No. 200 material while the contents of the flask are poured into a nest of No. 40 and No. 200 sieves.

6.3.1.4.6 After the minus No. 200 material has settled in the recovery container, carefully decant the water so that no minus No. 200 material is lost.

6.3.1.4.7 Dry the recovered minus No. 200 material to constant weight at a temperature that will not cause material to be lost due to splattering. Determine and record the weight of the recovered minus No. 200 material to the nearest 0.1 gram.

6.3.1.4.8 Combine the material retained on the No. 40 and No. 200 sieves and perform fan drying.

6.3.1.4.9 The weight of the recovered minus No. 200 material is added to the W_{sd} weight.

6.3.1.4.10 Using Equation 3, calculate the effective specific gravity of each RAP aggregate (G_{ser}).

Equation 3:

$$G_{ser} = \frac{100 - P_{brn}}{\dfrac{100}{G_{mmr}} - \dfrac{P_{brn}}{G_{brn}}}$$

Where:
- G_{ser} = Effective specific gravity of each RAP aggregate.
- P_{brn} = Binder content of material from each RAP stockpile.
- G_{mmr} = Maximum theoretical specific gravity of material from each RAP stockpile.
- G_{brn} = When >15% RAP binder is used, the tested specific gravity of the recovered RAP binder from each RAP stockpile. Alternatively, blended RAP binder from each RAP stockpile may be tested. (See Note 9.) When ≤15% RAP binder is used, an estimated specific gravity of 1.050 is used for the RAP binder.

Example [for RAP Aggregate 1 (Fine RAP)]:

P_{br1} = 5.82
G_{mmr} = 2.469
G_{br1} = 1.049

$$G_{ser} = \frac{100 - 5.82}{\frac{100}{2.469} - \frac{5.82}{1.049}} = 2.694$$

Example [for RAP Aggregate 2 (Coarse RAP)]:

P_{br2} = 3.43
G_{mmr} = 2.326
G_{br2} = 1.052

$$G_{ser} = \frac{100 - 3.43}{\frac{100}{2.326} - \frac{3.43}{1.052}} = 2.431$$

6.3.2 Using Equation 4a, calculate the Bulk Oven Dry Specific Gravity (G_{sbr}) of each RAP aggregate as a function of the estimated Binder Absorption of the RAP aggregate and the calculated Effective Specific Gravity.

Equation 4a: $$G_{sbr} = \frac{G_{ser}}{\frac{P_{bar} \times G_{ser}}{100 \times G_{brn}} + 1}$$

Where: G_{sbr} = Bulk oven dry specific gravity of each RAP aggregate.
P_{bar} = Estimated binder absorption of the RAP aggregate. (See Note 6.)

Example [for RAP Aggregate 1 (Fine RAP)]:

G_{ser} = 2.694
P_{bar} = 0.50
G_{br1} = 1.049

$$G_{sbr} = \frac{2.694}{\frac{0.50 \times 2.694}{100 \times 1.049} + 1} = 2.660$$

Example [for RAP Aggregate 2 (Coarse RAP)]:

G_{ser} = 2.431
P_{bar} = 0.50
G_{br2} = 1.052

$$G_{sbr} = \frac{2.431}{\frac{0.50 \ x \ 2.431}{100 \ x \ 1.052} + 1} = 2.403$$

6.4 Using Equation 4b, calculate the corresponding estimated S.S.D. specific gravity of each RAP aggregate.

Equation 4b: $$\begin{bmatrix}\text{S.S.D. Specific Gravity} \\ \text{of each RAP aggregate}\end{bmatrix} = G_{sbr} \ x \ \left(1 + \frac{A_v}{100}\right)$$

Where: G_{sbr} = Bulk oven dry specific gravity of each RAP aggregate.
A_v = Combined virgin aggregate water absorption without mineral admixture.

Note 7: The water absorption of the RAP aggregates is assumed to be the same as the combined virgin aggregate water absorption.

Example [for RAP Aggregate 1 (Fine RAP)]:

G_{sbr} = 2.660
A_v = 1.13

$$\begin{bmatrix}\text{S.S.D. Specific Gravity of} \\ \text{RAP aggregate 1 (Fine RAP)}\end{bmatrix} = 2.660 \ x \ \left(1 + \frac{1.13}{100}\right) = 2.690$$

Example [for RAP Aggregate 2 (Coarse RAP)]:

G_{sbr} = 2.403
A_v = 1.13

$$\begin{bmatrix}\text{S.S.D. Specific Gravity of} \\ \text{RAP aggregate 2 (Coarse RAP)}\end{bmatrix} = 2.403 \ x \ \left(1 + \frac{1.13}{100}\right) = 2.430$$

6.5 Using Equation 4c, calculate the corresponding estimated Apparent specific gravity of each RAP aggregate.

Equation 4c: $$\begin{bmatrix}\text{Apparent Specific Gravity} \\ \text{of each RAP aggregate}\end{bmatrix} = \frac{1}{\frac{1}{G_{sbr}} - \frac{A_v}{100}}$$

Where: G_{sbr} = Bulk oven dry specific gravity of each RAP aggregate.
A_v = Combined virgin aggregate water absorption without mineral admixture. (See Note 7.)

Example [for RAP Aggregate 1 (Fine RAP)]:

G_{sbr} = 2.660
A_v = 1.13

`

$$\begin{bmatrix} \text{Apparent Specific Gravity of} \\ \text{RAP aggregate 1 (Fine RAP)} \end{bmatrix} = \frac{1}{\frac{1}{2.660} - \frac{1.13}{100}} = 2.742$$

Example [for RAP Aggregate 2 (Coarse RAP)]:

G_{sbr} = 2.403
A_v = 1.13

$$\begin{bmatrix} \text{Apparent Specific Gravity of} \\ \text{RAP aggregate 2 (Coarse RAP)} \end{bmatrix} = \frac{1}{\frac{1}{2.403} - \frac{1.13}{100}} = 2.470$$

6.6 Using Equation 5, calculate the combined Bulk Oven Dry (G_{sb}) specific gravity, combined S.S.D. specific gravity, and combined Apparent specific gravity of the virgin aggregate, RAP aggregate, and mineral admixture.

Equation 5:

$$\begin{bmatrix} \text{Combined Specific Gravity} \\ \text{of Virgin Aggregate, RAP} \\ \text{Aggregate, and Mineral} \\ \text{Admixture} \end{bmatrix} = \frac{P_f + P_c + P_{ra1} + P_{ra2} + P_{admix}}{\frac{P_f}{G_f} + \frac{P_c}{G_c} + \frac{P_{ra1}}{G_{ra1}} + \frac{P_{ra2}}{G_{ra2}} + \frac{P_{admix}}{G_{admix}}}$$

Where: P_f = Weight percent of total virgin fine aggregate (minus No. 4), determined from Composite #1. [Calculated by multiplying the percentage of each virgin aggregate material used in the composite by the respective percent passing No. 4, and summing the individual results.]

P_c = Weight percent of total virgin coarse aggregate (plus No. 4), determined from Composite #1. [Calculated by subtracting P_f from the total percent virgin aggregate used in the composite.]

P_{ra1}, P_{ra2} = Weight percent of each RAP aggregate, determined from Composite #1.

P_{admix} = Percent mineral admixture by weight of the aggregate.

$P_f + P_c + P_{ra1} + P_{ra2}$ = 100

$P_f + P_c + P_{ra1} + P_{ra2} + P_{admix}$ = 100 + % Mineral Admixture

G_f, G_c, G_{ra1}, G_{ra2} = Bulk Oven Dry, SSD, or Apparent specific gravity of the virgin fine aggregate, virgin coarse aggregate, and RAP aggregate(s) respectively.

G_{admix} = Specific gravity of the mineral admixture.

Type I or II Cement = 3.14
Type IP Cement = 3.00
Hydrated Lime = 2.20

Example [for combined Bulk Oven Dry Specific Gravity (G_{sb})]:

G_f = 2.797
G_c = 2.789
G_{ra1} = G_{sbr} [for RAP Aggregate 1 (Fine RAP)] = 2.660
G_{ra2} = G_{sbr} [for RAP Aggregate 2 (Coarse RAP)] = 2.403
G_{admix} = 3.00 (Type IP Cement)
P_f = (0.35 x 97.1) + (0.13 x 98.8) + (0.08 x 22.5) + (0.19 x 1.6) = 48.93
P_c = (75 – 48.93) = 26.07
P_{ra1} = 15.0 [for RAP Aggregate 1 (Fine RAP)]
P_{ra2} = 10.0 [for RAP Aggregate 2 (Coarse RAP)]
P_{admix} = 1.0

$$\begin{bmatrix}\text{Example of Combined} \\ \text{Bulk Oven Dry Specific} \\ \text{Gravity } (G_{sb}) \text{ of Virgin} \\ \text{Aggregate, RAP} \\ \text{Aggregate, and Mineral} \\ \text{Admixture}\end{bmatrix} = \frac{48.93 + 26.07 + 15.0 + 10.0 + 1.0}{\frac{48.93}{2.797} + \frac{26.07}{2.789} + \frac{15.0}{2.660} + \frac{10.0}{2.403} + \frac{1.0}{3.00}} = 2.732$$

6.7 Using Equation 6, calculate the combined water absorption of the virgin aggregate, RAP aggregate, and mineral admixture.

***Equation 6*:**

$$\begin{bmatrix}\text{Combined Water} \\ \text{Absorption of} \\ \text{Virgin Aggregate,} \\ \text{RAP Aggregate,} \\ \text{and Mineral} \\ \text{Admixture}\end{bmatrix} = \frac{(P_f \text{ x } A_f) + (P_c \text{ x } A_c) + (P_{ra} \text{ x } A_v) + (P_{admix} \text{ x } A_{admix})}{P_f + P_c + P_{ra} + P_{admix}}$$

Where: P_f, P_c, = Weight percent of virgin fine aggregate (minus No. 4) and virgin coarse aggregate (plus No. 4), respectively, as determined for P_f and P_c for use in Equation 5.

P_{ra} = Total percent of RAP aggregate (Determined from Composite #1).

A_v = Combined virgin aggregate water absorption without mineral admixture. (See Note 7.)

P_{admix} = Percent mineral admixture by weight of the aggregate.

$P_f + P_c + P_{ra}$ = 100

$P_f + P_c + P_{ra} + P_{admix}$ = 100 + % Mineral Admixture

A_f, A_c = Percent water absorption of the virgin fine aggregate and the virgin coarse aggregate respectively.

A_{admix} = Percent water absorption of mineral admixture (<u>assumed to be 0.0%</u>).

Example:

P_f = 48.93
P_c = 26.07
A_f = 1.11
A_c = 1.17
P_{ra} = 25.0
A_v = 1.13
P_{admix} = 1.0
A_{admix} = 0.00

$$\begin{bmatrix} \text{Combined Water} \\ \text{Absorption of} \\ \text{Virgin Aggregate,} \\ \text{RAP Aggregate,} \\ \text{and Mineral} \\ \text{Admixture} \end{bmatrix} = \frac{(48.93 \text{ x } 1.11) + (26.07 \text{ x } 1.17) + (25.0 \text{ x } 1.13) + (1.0 \text{ x } 0.00)}{48.93 + 26.07 + 25.0 + 1.0} = 1.13$$

7. ASPHALT BINDER SELECTION

7.1 Estimate the total binder content that will be needed in the mix design and determine whether the RAP binder content is lower or higher than the estimated total binder content.

Note 8: Estimating the total binder content relative to the RAP binder content may assist the designer in estimating the amount of RAP material which can be used in the mix.

7.2 For mixes utilizing >15% RAP binder, the extract obtained from the solvent extraction of material from each RAP stockpile, performed in Subsection 5.2.1.3, is used for additional testing. Determine and remove mineral matter from the extract using AASHTO T 164, Annex Method A1.2 (Centrifuge).

7.3 For mixes utilizing ≤15% RAP binder, the virgin binder used in the mix design shall be the grade called for in the Special Provisions. Determine the specific gravity [AASHTO T 228 (at 77 °F)] of the virgin binder.

7.4 For mixes utilizing >15% RAP binder, the virgin binder used in the mix design will be the grade determined as follows:

7.4.1 Recover the RAP binder from the extract solvent from each RAP stockpile using either AASHTO T 170 or ASTM D 5404. The solvent used in the extraction process shall not contain stabilizers that act as acid scavengers. The entire procedure, from the start of the extraction to the final recovery, must be completed within eight hours.

7.4.2 Perform PG grading (AASHTO R 29) on the recovered RAP binder from each RAP stockpile. Rotational viscosity, flash point, and mass loss tests are not required. Use PAV aging temperature for grade specified in the Special Provisions. Determine the specific gravity [AASHTO T 228 (at 77 °F)] of the recovered RAP binder from each RAP stockpile.

Note 9: Alternatively, the recovered binder from each RAP stockpile may be proportionally blended and the PG grading and specific gravity determined on the blended RAP binder.

7.4.3 Perform PG verification (AASHTO R 29) and determine the specific gravity [AASHTO T 228 (at 77 °F)] of the virgin binder, or use PG verification and specific gravity provided by the virgin asphalt binder supplier.

7.4.4 Blend RAP binder and virgin binder using the following procedure.

7.4.4.1 Using Equation 7, calculate the percent of RAP binder to blend with virgin binder. The percent of RAP binder, by weight of the total binder in the mix, shall not exceed the allowable maximum specified.

Equation 7:

$$P_{rb} = \frac{\left(\dfrac{\frac{P_{ra1}}{100}}{100 - P_{br1}} \text{ x } P_{br1}\right) + \left(\dfrac{\frac{P_{ra2}}{100}}{100 - P_{br2}} \text{ x } P_{br2}\right)}{\dfrac{1 + \frac{P_{admix}}{100}}{100 - P_b} \text{ x } P_b} \text{ x } 100$$

Where: P_{rb} = Percent of RAP Binder to blend with Virgin binder (Percent of RAP binder, by weight of total binder, in the mix).

P_{ra1}, P_{ra2} = Percent of RAP aggregate from each RAP stockpile (from Composite #1).

P_{br1}, P_{br2} = Binder content of the material from each RAP stockpile.

P_{admix} = Percent mineral admixture used.

P_b = Total asphalt binder content (percent by total weight of the bituminous mixture).

Note 10: The total asphalt binder content estimated in Subsection 7.1 is initially used for the value of P_b in Equations 7, 7a, and 7b. Subsequently, the actual total asphalt binder content from the mix design shall be used for the value of P_b.

Example:

$$P_{ra1} = 15.0$$
$$P_{ra2} = 10.0$$
$$P_{br1} = 5.82$$
$$P_{br2} = 3.43$$
$$P_{admix} = 1.0$$
$$P_b = 5.40$$

$$P_{rb} = \frac{\left(\dfrac{\frac{15.0}{100}}{100 - 5.82} \times 5.82\right) + \left(\dfrac{\frac{10.0}{100}}{100 - 3.43} \times 3.43\right)}{\dfrac{1 + \frac{1.0}{100}}{100 - 5.40} \times 5.40} \times 100 = 22.24\%$$

7.4.4.2 The proportional amount of RAP binder from each RAP stockpile can be calculated using Equations 7a and 7b.

Equation 7a:

$$P_{rb1} = \frac{\dfrac{\frac{P_{r1}}{100}}{100 - P_{br1}} \times P_{br1}}{\dfrac{1 + \frac{P_{admix}}{100}}{100 - P_b} \times P_b} \times 100$$

Example (for Equation 7a) [for RAP Stockpile 1 (Fine RAP)]:

$$P_{rb1} = \frac{\dfrac{\frac{15.0}{100}}{100 - 5.82} \times 5.82}{\dfrac{1 + \frac{1.0}{100}}{100 - 5.4} \times 5.4} \times 100 = 16.08\%$$

Equation 7b:

$$P_{rb2} = \frac{\dfrac{\frac{P_{r2}}{100}}{100 - P_{br2}} \times P_{br2}}{\dfrac{1 + \frac{P_{admix}}{100}}{100 - P_b} \times P_b} \times 100$$

Example (for Equation 7b) [for RAP Stockpile 2 (Coarse RAP)]:

$$P_{rb2} = \frac{\dfrac{\frac{10.0}{100}}{100 - 3.43} \times 3.43}{1 + \dfrac{\frac{1.0}{100}}{100 - 5.4} \times 5.4} \times 100 = 6.16\%$$

7.4.4.3 Blend the required amount of RAP binder (proportional amounts from each RAP stockpile if necessary) with the required amount of virgin binder. The RAP binder and the virgin binder shall be heated sufficiently to pour and thoroughly stirred prior to blending. The blended material shall be thoroughly stirred prior to testing.

7.4.5 Perform PG verification (AASHTO R 29) on the blend of RAP and virgin binder. Flash point and mass loss tests are not required.

Note 11: If the total binder content, estimated in Subsection 7.1, deviates by more than 0.30 percent from the total binder content established by mix design, the PG grading must be verified on a binder blended at the blend percentages established by the mix design.

7.4.6 If the blended binder does not meet the specified grade, a different virgin binder grade, or a different proportion of RAP and virgin binder, must be selected. An iterative process may be required in order to obtain a final blend of RAP and virgin binder that meets the specified binder grade.

Note 12: The virgin binder grade may only be changed one PG grade (6 °C on either or both the high and low temperatures) from that shown in the bid documents.

7.4.7 Determine the specific gravity [AASHTO T 228 (at 77 °F)] of the blended binder. Develop a viscosity - temperature curve (ASTM D 2493) for the blended binder.

8. LABORATORY MIXING AND COMPACTION TEMPERTURES

8.1 For mixes containing ≤15% RAP binder, the laboratory mixing and compaction temperatures shall be determined based on the specified virgin binder utilized. These temperatures are determined in accordance with Subsections 8.1.1 through 8.1.4 below.

8.1.1 The rotational viscosity of the asphalt binder at 275 °F and 350 °F shall be determined in accordance with AASHTO T 316, and a viscosity - temperature curve developed in accordance with ASTM D 2493.

8.1.2 The laboratory mixing temperature range is defined as the range of temperatures where the un-aged asphalt binder has a rotational viscosity of 0.17 ± 0.02 Pascal·seconds. The actual laboratory mixing temperature used is normally selected at or near the mid-point of the range.

8.1.3 The laboratory compaction temperature range is defined as the range of temperatures where the un-aged asphalt binder has a rotational viscosity of 0.28 ± 0.03 Pascal·seconds. The actual laboratory compaction temperature used is normally selected at or near the mid-point of the range.

8.1.4 The viscosity - temperature curve shall be included in the mix design report. For PG asphalt binders that have a maximum laboratory mixing temperature exceeding 325 °F or a maximum laboratory compaction temperature exceeding 300 °F, the laboratory mixing and compaction temperature ranges shall be specified in writing by the asphalt binder supplier. A viscosity-temperature curve will meet this requirement for written documentation if the viscosity-temperature curve is developed and submitted by the binder supplier and includes language that the recommended laboratory mixing and compaction temperatures are within acceptable ranges, and shall include a statement indicating the maximum laboratory mixing temperature to which the binder can be heated without damage. The laboratory mixing and compaction temperature ranges, as well as the actual laboratory mixing and compaction temperatures used, shall be reported on the mix design.

8.2 For mixes containing >15% RAP binder, the laboratory mixing and compaction temperatures shall be determined from a viscosity - temperature curve developed for the blended binder. These temperatures are determined in accordance with Subsections 8.2.1 through 8.2.5 below.

8.2.1 The rotational viscosity of the blended binder at 275 °F and 350 °F shall be determined in accordance with AASHTO T 316, and a viscosity - temperature curve developed in accordance with ASTM D 2493.

8.2.2 Determine the laboratory mixing temperature range and the laboratory compaction temperature range, along with the actual laboratory mixing and compaction temperatures, in accordance with Subsections 8.1.2 and 8.1.3.

8.2.3 If the maximum laboratory mixing temperature exceeds 350 ^{o}F, a temperature of 350 ^{o}F shall be used.

8.2.4 If the maximum laboratory compaction temperature exceeds 325 ^{o}F, a temperature of 325 ^{o}F shall be used.

8.2.5 The viscosity - temperature curve shall be included in the mix design report. The laboratory mixing and compaction temperature ranges, as well as the actual laboratory mixing and compaction temperatures used, shall be reported on the mix design.

9. PREPARATION OF SPECIMENS FOR BULK SPECIFIC GRAVITY/BULK DENSITY AND MARSHALL STABILITY/FLOW DETERMINATION

9.1 Specimens shall be prepared as described herein, utilizing the apparatus specified in ARIZ 410.

Note 13: A minimum of three different asphalt binder contents at 0.5% increments is required, although in some cases it may be necessary to prepare additional sets of samples at other asphalt binder contents.

9.2 The virgin aggregate-RAP-mineral admixture samples, prepared as specified in Section 5, shall be dried to constant weight at the laboratory mixing temperature $\pm$ 5 ºF and shall be at this temperature at the time of mixing with the virgin asphalt binder. If necessary, a small amount of proportioned minus No. 8 virgin aggregate make-up material shall be added to bring samples to the desired weight.

9.3 Before each batch of asphaltic concrete is mixed, the virgin asphalt binder shall be heated in a loosely covered container in a forced draft oven for approximately 2 hours or as necessary to bring the asphalt binder to the laboratory mixing temperature $\pm$ 5 ºF.

9.4 The weight of virgin asphalt binder required to provide the desired total binder content shall be calculated as follows.

9.4.1 The total binder content of a mix design sample is the total of the added virgin asphalt binder plus the RAP binder. Using Equations 8 through 10, calculate the weight of virgin asphalt binder (W_{vb}) to be added to the virgin aggregate-dry screened RAP-mineral admixture sample.

Equation 8: $$W_b = \frac{W_s + W_a}{100 - P_b} \times P_b$$

Equation 9: (Calculated for each RAP stockpile)

$$W_{rbn} = \frac{\frac{P_{ran}}{100} \times W_s}{100 - P_{brn}} \times P_{brn}$$

Equation 10: $$W_{vb} = W_b - \left[W_{rb1} + W_{rb2} \right]$$

Where:
W_b = Weight of Total Binder (virgin asphalt binder + RAP binder).
W_s = Weight of Total Aggregate (virgin aggregate + RAP aggregate).
W_a = Weight of Mineral Admixture.
P_b = Percent Total Binder (virgin asphalt binder + RAP binder) for each asphalt binder content, by total weight of mix.
W_{rbn} = Weight of RAP binder for each RAP stockpile.
P_{ran} = Percent of each RAP aggregate used (Determined from Composite #1).
P_{brn} = Binder content of the material from each RAP stockpile.
W_{vb} = Weight of virgin asphalt binder.

Example (for 5.0% asphalt binder content) (See Note 13.):

W_s = 3300 g
W_a = 33 g
P_b = 5.0%
P_{ra1} = 15.0%
P_{ra2} = 10.0%
P_{br1} = 5.82%
P_{br2} = 3.43%

$$W_b = \frac{3300 + 33}{100 - 5.0} \times 5.0 = 175.4 \text{ grams}$$

For RAP Stockpile 1 (Fine RAP): $$W_{rb} = \frac{\frac{15.0}{100} \times 3300}{100 - 5.82} \times 5.82 = 30.6 \text{ grams}$$

For RAP Stockpile 2 (Coarse RAP): $W_{rb} = \dfrac{\dfrac{10.0}{100} \times 3300}{100 - 3.43} \times 3.43 = 11.7$ grams

$$W_{vb} = 175.4 - [30.6 + 11.7] = 133.1 \text{ grams}$$

Note 14: Before each batch is mixed, the mixing bowl and whip shall be heated to the laboratory mixing temperature ± 5 ºF.

9.5 The virgin aggregate-RAP-mineral admixture blend and the appropriate amount of virgin asphalt binder shall be mixed together for 90 to 120 seconds at the required laboratory mixing temperature ± 5 ºF. **Mechanical mixing is required.**

Note 15: Although a wide range of mixers may provide the desired well-coated homogeneous mixture, commercial dough mixers with whips are often used. Minimum recommended capacity of the mixing bowl is 12 quarts.

Note 16: After mechanical mixing, hand mixing shall be used as necessary to produce a well-coated homogeneous mixture.

9.6 Immediately after mixing, each batch shall be thoroughly blended and spread according to ARIZ 416. The circular mass shall be cut into 6 equal pie-shaped segments. Take opposite segments for each individual specimen and use up the entire batch.

9.7 Each individual specimen shall be spread in a large pan at nominal single-stone thickness. Avoid stacking particles as feasible. The specimens shall be oven-cured for 2 hours ± 10 minutes at the laboratory compaction temperature ± 5 ºF.

9.8 A mold assembly (base plate, mold, and collar) shall be heated to the laboratory compaction temperature ± 5 ºF. The face of the compaction hammer shall be thoroughly cleaned and heated on a hot plate set at the laboratory compaction temperature ± 5 ºF. A suitable shield, baffle plate, or sand bath shall be used on the surface of the hot plate to minimize localized overheating of the face of the hammer.

9.9 Place a 4-inch diameter paper disc in the bottom of the mold before the mixture is introduced. Quickly place the mixture into the mold using a transfer bowl or other suitable device. Spade the mixture vigorously with a heated flat metal spatula, with a blade approximately 1-inch wide and 6-inches long and stiff enough to penetrate the entire layer of material, 15 times around the perimeter and 10 times at random into the mixture, penetrating the mixture to the bottom of the mold. Smooth the surface of mix to a slightly rounded shape.

9.10 Before compaction, put the mold containing the mixture in an oven as necessary to heat the mixture to the laboratory compaction temperature ± 5 ºF. The specimen shall not be heated for more than one hour after being placed in the mold. Prior to compaction, it shall be verified that the mixture is at the required temperature. An electronic temperature probe with a digital display or a long-stem metal thermometer with a dial face shall be used. The use of an infrared temperature gun is not allowed.

9.11 Immediately upon removing the mold assembly loaded with mix from the oven, place a paper disc on top of mixture, place the mold assembly on the compaction pedestal in the mold holder, and apply 75 blows with the compaction hammer. Remove the base plate and collar, and reverse and reassemble the mold. Apply 75 compaction blows to the face of the reversed specimen.

Note 17: The compaction hammer shall apply only one blow after each fall, that is, there shall not be a rebound impact. The compaction hammer shall meet the requirements specified in Subsection 2.4 of ARIZ 410.

9.12 Remove the collar and top paper disc. Remove the base plate and remove the bottom paper disc while the specimen is still hot.

Note 18: Paper discs need to be removed while the specimen is hot. The discs are difficult to remove after the specimens have cooled.

9.13 Allow each compacted specimen to cool until they can be extruded without damaging the specimen.

Note 19: Generally, specimens can be extruded without damage when they are at a temperature of approximately 77 to 90 ºF.

Note 20: Cooling may be accomplished at room temperature, or in a 77 °F air bath. If more rapid cooling is desired, the mold and specimen may be placed in front of a fan until cool.

9.14 Extrude the specimen by orienting the mold so that the ram pushes on the bottom face (base plate face) of the specimen. If any specimen is deformed or damaged during extrusion, the entire set of specimens at that asphalt binder content shall be discarded and a new set prepared.

9.15 Immediately upon extrusion, measure and record the height of the specimen to the nearest 0.001 inch and determine and record its weight in air to the nearest 0.1 gram. Compacted specimens shall be 2.500 ± 0.200 inches in height. If this criteria is not met for the specimens at each asphalt binder content, the entire set of specimens at that asphalt binder content shall be discarded and a new set prepared after necessary adjustments in the sample size have been made using Equation 2. (See Note 4 in Table 2.)

9.16 Repeat the procedures in Subsections 9.4 through 9.15 for the required specimens.

10. BULK SPECIFIC GRAVITY/BULK DENSITY OF SPECIMENS

10.1 Determine the bulk specific gravity and bulk density of the three compacted specimens at each asphalt binder content in accordance with ARIZ 415, Method A. The determination of the “Weight in Water” and “S.S.D. Weight" of each specimen will be completed before the next specimen is submerged for its "Weight in Water" determination.

Note 21: Specimens fabricated in the laboratory that have not been exposed to moisture do not require drying after extrusion from the molds. The specimen weight in air obtained in Subsection 10.1 is its dry weight.

10.2 For each asphalt binder content, the densities of individual compacted specimens shall not differ by more than 2.0 pcf. If this density requirement is not met, the entire set of specimens at that asphalt binder content shall be discarded and a new set of specimens prepared.

10.3 For each set of three specimens, determine the average bulk specific gravity (G_{mb}), and using that value calculate the average bulk density (G_{mb} multiplied by 62.3 lb./cu. ft.).

11. MARSHALL STABILITY AND FLOW DETERMINATION

11.1 Specimens shall be tested for Marshall Stability and Flow utilizing the apparatus specified in ARIZ 410.

11.2 For each specimen, determine the uncorrected stability, the stability (corrected for height), and the flow according to ARIZ 410, Subsections 4.6 through 4.11. In addition, determine the average stability (corrected for height) and average flow for each set of specimens prepared at each asphalt binder content.

12. MAXIMUM THEORETICAL SPECIFIC GRAVITY (RICE TEST)

12.1 The maximum theoretical specific gravity of the mixture shall be determined in accordance with ARIZ 806, with the following modifications:

12.1.1 Prepare the specimens including mineral admixture according to the procedures described in Section 5 and Subsections 9.2 through 9.5 using 5.5% or 6.0% total asphalt binder (virgin binder plus RAP binder) by total mix weight. A liquid anti-stripping agent is not used.

12.1.2 Immediately after mixing, the material shall be thoroughly blended and spread according to the procedures described in ARIZ 416. The circular mass shall be cut into 6 equal pie-shaped segments. Take opposite segments for each individual test sample and use up the entire batch.

12.1.3 Each individual test sample shall be spread in a large pan at nominal single-stone thickness. Avoid stacking particles as feasible. The test samples shall be oven-cured for 2 hours ± 10 minutes at the laboratory compaction temperature ± 5 °F.

12.1.4 After curing, each test sample shall be spread on a sheet of heavy paper or in a large flat bottom pan. Before the samples are completely cooled, separate the particles of the mixture, taking care not to fracture the mineral aggregate particles, so that the particles of the fine aggregate portion are not larger than ¼ inch. Allow the test samples to cool to room temperature.

12.1.5 Using Equation 11, calculate the effective specific gravity of the combined virgin aggregate, RAP aggregate, and mineral admixture (G_{se}).

Equation 11:

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

Where:

G_{se} = Effective specific gravity of the combined virgin aggregate, RAP aggregate, and mineral admixture.

P_b = Total asphalt binder content (virgin binder + RAP binder) at which the Rice test was performed (Rice P_b).

G_{mm} = Measured maximum theoretical specific gravity of the mix at Rice P_b.

G_b = When >15% RAP binder is used, the specific gravity of the blended virgin and RAP binder. (When ≤15% RAP binder is used, the specific gravity of the virgin binder is used for the value of G_b.)

Example:

P_b = 6.0
G_{mm} = 2.526
G_b = 1.031

$$G_{se} = \frac{100 - 6.0}{\frac{100}{2.526} - \frac{6.0}{1.031}} = 2.784$$

12.1.6 Using Equation 12, calculate the maximum theoretical specific gravity (G_{mm}) for each asphalt binder content.

Note 22: G_{se} is considered constant regardless of asphalt binder content.

Equation 12:

$$G_{mm} = \frac{100}{\frac{P_{sa}}{G_{se}} + \frac{P_b}{G_b}}$$

Where:

G_{mm} = Calculated maximum theoretical specific gravity of the mix at each asphalt binder content P_b.

P_{sa} = Aggregate and mineral admixture content, percent by total weight of mix (100-P_b).

P_b = Percent asphalt binder, by total weight of mix, for each asphalt binder content.

G_{se} = Effective specific gravity of the combined virgin aggregate, RAP aggregate, and mineral admixture.

G_b = When >15% RAP binder is used, the specific gravity of the blended virgin and RAP binder. (When ≤15% RAP binder is used, the specific gravity of the virgin binder is used for the value of G_b.)

Example (for 5.0% asphalt binder content) (See Note 13.):

P_{sa} = 95.0
P_b = 5.0
G_{se} = 2.784
G_b = 1.031

$$G_{mm} = \frac{100}{\frac{95.0}{2.784} + \frac{5.0}{1.031}} = 2.566$$

13. DETERMINATION OF DESIGN ASPHALT BINDER CONTENT

13.1 The design percent asphalt binder content is determined as follows in Subsections 13.2 and 13.3.

13.2 For each asphalt binder content used, calculate effective voids (V_a), percent absorbed asphalt (P_{ba}), voids in mineral aggregate (VMA), percent effective asphalt binder content (P_{be}), and the ratio of the mix design composite gradation target for the No. 200 sieve, including mineral admixture, to the effective asphalt binder content (Dust/Bitumen Ratio) using the following equations.

13.2.1 Using Equation 13, calculate the effective voids (V_a). The calculated G_{mm} values for the respective asphalt binder contents are used to determine the corresponding effective voids content of the compacted Marshall specimens at each asphalt binder content.

Equation 13: $$V_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100$$

Where: V_a = Effective voids in the compacted mixture, percent of total volume.

G_{mm} = Calculated maximum theoretical specific gravity of the mix at each asphalt binder content P_b.

G_{mb} = Bulk specific gravity of compacted mixture specimens.

Example (for 5.0% asphalt binder content) (See Note 13.):

G_{mm} = 2.566
G_{mb} = 2.400

$$V_a = \frac{2.566 - 2.400}{2.566} \times 100 = 6.5$$

13.2.2 Using Equation 14, calculate the percent absorbed asphalt (P_{ba}).

Note 23: The percent absorbed asphalt (P_{ba}) is the same for all binder contents.

Equation 14:

$$P_{ba} = \frac{G_{se} - G_{sb}}{G_{sb} \times G_{se}} \times G_b \times 100$$

Where: P_{ba} = Absorbed asphalt, percent by total weight of mix.

G_{se} = Effective specific gravity of the combined virgin aggregate, RAP aggregate, and mineral admixture.

G_{sb} = Bulk oven dry specific gravity of the combined virgin aggregate, RAP aggregate, and mineral admixture.

G_b = When >15% RAP binder is used, the specific gravity of the blended virgin and RAP binder. (When ≤15% RAP binder is used, the specific gravity of the virgin binder is used for the value of G_b.)

Example:

G_{se} = 2.784
G_{sb} = 2.732
G_b = 1.031

$$P_{ba} = \frac{2.784 - 2.732}{2.732 \times 2.784} \times 1.031 \times 100 = 0.70$$

13.2.3 Using Equation 15, calculate voids in mineral aggregate (VMA) of the compacted Marshall specimens at each asphalt binder content.

Equation 15: $$VMA = 100 - \frac{G_{mb} \times P_{sa}}{G_{sb}}$$

Where: VMA = Voids in the mineral aggregate, percent of bulk volume.
G_{mb} = Bulk specific gravity of compacted mixture specimens.
P_{sa} = Aggregate and mineral admixture content, percent by total weight of mix (100-P_b).
G_{sb} = Bulk oven dry specific gravity of the combined virgin aggregate, RAP aggregate, and mineral admixture.

Example (for 5.0% asphalt binder content) (See Note 13.):

G_{mb} = 2.400
P_{sa} = 95.0
G_{sb} = 2.732

$$VMA = 100 - \frac{2.400 \times 95.0}{2.732} = 16.5$$

13.2.4 Using Equation 16, calculate the percent effective asphalt binder content (P_{be}) of the compacted Marshall specimens at each asphalt binder content.

Equation 16: $$P_{be} = P_b - \frac{P_{ba} \times P_{sa}}{100}$$

Where: P_{be} = Percent effective asphalt binder content of the mixture (free binder not absorbed).
P_b = Asphalt binder content, percent by total weight of mix.
P_{ba} = Absorbed asphalt, percent by total weight of mix.
P_{sa} = Aggregate and mineral admixture content, percent by total weight of mix (100-P_b).

Example (for 5.0% asphalt binder content) (See Note 13.):

P_b = 5.0
P_{ba} = 0.70
P_{sa} = 95.0

$$P_{be} = 5.0 - \frac{0.70 \times 95.0}{100} = 4.34$$

13.2.5 Using Equation 17, calculate the the ratio of the mix design composite gradation target for the No. 200 sieve, including mineral admixture, to the effective asphalt binder content (Dust/Bitumen Ratio) of the compacted Marshall specimens at each asphalt binder content.

Equation 17: $$\text{Dust / Bitumen Ratio} = \frac{\begin{bmatrix}\text{Mix Design} \\ \text{Passing No. 200} \\ \text{(Including Mineral Admix.)}\end{bmatrix}}{P_{be}}$$

Where: P_{be} = Percent effective asphalt binder content of the mixture (free binder not absorbed).

Example (for 5.0% asphalt binder content) (See Note 13.):

P_{be} = 4.34

$$\text{Dust / Bitumen Ratio} = \frac{5.2}{4.34} = 1.20$$

13.3 If the specified value for effective voids (V_a) falls between the resultant V_a values determined for two of the asphalt binder contents used, ~~line~~ straight-line interpolation shall be used to calculate the bulk specific gravity (G_{mb}) at each 0.1% asphalt binder content increment between the two corresponding measured values of G_{mb}. Using equations 12 and 13, determine the values for G_{mm} and V_a at each interpolated asphalt binder content. Select the total asphalt binder content which results in V_a being as close as possible to the specified value.

13.3.1 Using equations 15, 16, and 17, calculate VMA, P_{be}, and the Dust/Bitumen Ratio at the selected asphalt binder content. Using straight-line interpolation, determine the values for stability and flow that correspond to the selected asphalt binder content. If the values for VMA, Dust/Bitumen Ratio, stability, and flow are within the limits of the specifications, the selected asphalt binder content shall be the design asphalt binder content.

13.3.2 On separate graphs (using the same scale for percent total asphalt binder for each graph), plot the values for bulk specific gravity, effective voids, VMA, Dust/Bitumen Ratio, stability, and flow for each set of three specimens and at the design asphalt binder content, versus the percent total asphalt binder. Draw a smooth "best fit" based on the plotted points, as shown in Figure 7. The graphs in Figure 7 are for illustrative purposes only. Straight-line interpolation, as specified in Subsections 13.3 and 13.3.1, is used for mix design calculations.

13.3.3 If it is not possible to obtain specification compliance within the range of asphalt binder contents used, a determination must be made to either redesign the mix (different aggregate gradation and/or source) or prepare additional specimens at other asphalt binder contents for testing and volumetric analyses.

14. IMMERSION COMPRESSION (IMC) TEST

14.1 The Immersion Compression Test shall be performed in accordance with ARIZ 802, modified as follows:

14.1.1 Prepare the asphaltic concrete sample including mineral admixture according to the procedures described in Section 5 and Subsections 9.2 through 9.5 at the design asphalt binder content.

14.1.2 Immediately after mixing, each batch shall be thoroughly blended and spread according to ARIZ 416. The circular mass shall be cut into 4 equal pie-shaped segments. Take opposite segments for each individual specimen and use up the entire batch.

14.1.3 Each individual sample shall be spread in a large pan at nominal single-stone thickness. Avoid stacking particles as feasible. The samples shall be oven-cured for 2 hours ± 10 minutes at 255 ± 5 ºF.

14.1.4 Compacted specimens shall be 4.000 ± 0.100 inches in height.

15. MIX DESIGN GRADATION TARGET VALUES

15.1 The target values for the combined virgin aggregate and RAP aggregate without mineral admixture (Composite #1), and the combined virgin aggregate-RAP aggregate-mineral admixture blend (Composite #1), in the mixture shall be expressed as percent passing particular sieve sizes as required by the specifications for the project.

16. REPORT

16.1 Report the test results and data obtained on the appropriate form. Liberal use of the remarks area to clarify and/or emphasize any element of the design is strongly recommended. Information required in the mix design report includes the items listed below. In addition, all composites and batch sheets/weigh-ups (examples are given in Figures 1 through 6) are to be included in the mix design report.

16.1.1 Name and address of the testing organization and the signature and seal of the mix design engineer responsible for the mix design.

16.1.2 Virgin Aggregate:

- Source and identification
- Individual stockpile or bin gradations
- Aggregate blend proportions and composite gradation with and without mineral admixture (See example in Figure 3.)
- Fine and coarse aggregate specific gravities (Bulk Oven Dry, SSD, Apparent) and absorption
- Combined Bulk Oven Dry Specific Gravity
- Combined Absorption
- Aggregate quality:
    - LA Abrasion
    - Sand Equivalent
    - Uncompacted Void Content (when applicable)

16.1.3 Mineral Admixture:

- Type and source
- Percentage used
- Specific gravity

16.1.4 RAP (each stockpile):

- Source and identification
- Anticipated gradation
- Binder content (P_{brn})
- Maximum theoretical specific gravity

16.1.5 RAP Aggregate (each stockpile):

- Percentage used
- Gradation
- Estimated binder absorption (P_{bar}) (normally 0.50 percent) (See Note 6.)
- Estimated Bulk Oven Dry, S.S.D., and Apparent specific gravities
- Aggregate quality:
    - LA Abrasion

16.1.6 Combined Virgin Aggregate and RAP Aggregate:

- Composite gradation with and without mineral admixture (See example in Figure 1.)
- Aggregate quality:
    - Fractured Coarse Aggregate Particles (percentage with one fractured face and when required, percentage with two fractured faces)
    - Carbonates (when applicable)

16.1.7 Virgin Asphalt Binder:

- Source and grade
- Specific gravity (at 77 °F)
- Viscosity - Temperature Curve and the following:
    - Laboratory mixing temperature range and actual laboratory mixing temperature used.
    - Laboratory compaction temperature range and actual laboratory compaction temperature used.
- Virgin asphalt binder content (by weight of total binder and by weight of total mix)
- PG verification results (if RAP binder content is greater than 15 percent)

16.1.8 RAP Binder:

- RAP binder content (by weight of total binder and by weight of total mix)
- PG grading results (Standard PG Grade and Actual Grade), including specific gravity (G_{brn}) (at 77 °F), on recovered RAP binder from each RAP stockpile (if RAP binder content is greater than 15 percent)

16.1.9 Virgin Asphalt Binder and RAP Binder Blend:

- Total Binder Content (P_b)
- PG verification results, including specific gravity (G_b) (at 77 °F), (if RAP binder content is greater than 15 percent)

16.1.10 Combined Virgin Aggregate and Dry Screened RAP:

- Individual stockpile or bin gradations
- Percentage of virgin aggregates used
- Percentage of RAP materials used (adjusted for RAP binder content)

16.1.11 Combined Aggregate (virgin aggregate and RAP aggregate) and Mineral Admixture:

- Combined specific gravities [Bulk Oven Dry (G_{sb}), SSD, and Apparent]
- Combined absorption

16.1.12 Maximum theoretical specific gravity (G_{mm}) and density (pcf) at the total asphalt binder content at which the Rice test was performed (Rice P_b).

16.1.13 Mixture Compaction Trials:

- Percent virgin asphalt binder, by weight of total binder in the mix
- Percent RAP binder, by weight of total binder in the mix
- Total asphalt binder content (P_b), by weight of the bituminous mixture
- Combined aggregate (virgin aggregate and RAP aggregate) and mineral admixture content (P_{sa})
- Calculated maximum theoretical specific gravity (G_{mm}) and density (pcf)
- Bulk specific gravity (G_{mb}) and bulk density (pcf) of Marshall specimens
- Percent effective voids (V_a)
- Percent voids in mineral aggregate (VMA)
- Dust/Bitumen Ratio
- Percent absorbed asphalt (P_{ba})
- Effective specific gravity of the combined aggregate (virgin aggregate and RAP aggregate) and mineral admixture (G_{se})
- Percent effective asphalt binder content (P_{be})
- Marshall stability (nearest 10 pounds)
- Marshall flow (0.01 inch)

16.1.14 Plots of the following properties versus percent total asphalt binder (See examples in Figure 7.):

- Percent effective voids (V_a)
- Percent voids in mineral aggregate (VMA)
- Dust/Bitumen Ratio
- Bulk specific gravity (G_{mb})
- Marshall stability
- Marshall flow

16.1.15 Mixture Properties at Design Asphalt Binder Content:

- Percent virgin asphalt binder, by weight of total binder in the mix
- Percent RAP binder, by weight of total binder in the mix
- Total asphalt binder content (P_b), by weight of the bituminous mixture
- Combined aggregate (virgin aggregate and RAP aggregate) and mineral admixture content (P_{sa})
- Calculated maximum theoretical specific gravity (G_{mm}) and density (pcf)
- Bulk specific gravity (G_{mb}) and bulk density (pcf) of Marshall specimens
- Percent effective voids (V_a)
- Percent voids in mineral aggregate (VMA)
- Dust/Bitumen Ratio
- Percent absorbed asphalt (P_{ba})
- Effective specific gravity of the combined aggregate (virgin aggregate and RAP aggregate) and mineral admixture (G_{se})
- Percent effective asphalt binder content (P_{be})
- Marshall stability (nearest 10 pounds)
- Marshall flow (0.01 inch)
- Immersion Compression wet strength (psi)
- Immersion Compression dry strength (psi)
- Index of retained strength

16.1.16 Mix Design Summary [The Mix Design Summary shall contain the information shown in Figure 8. (Pages 1 and 2 of an example Mix Design Summary for an Asphaltic Concrete Marshall Mix Design with RAP.)]

Example of Composite #1
(Virgin Aggregate and RAP Aggregate)

Material	Virgin Aggregate (75.0%)				RAP Aggregate (25.0%)		Composite		Specifications ADOT 416 (3/4 Inch Special Mix)	
	Washed Crusher Fines	Crusher Fines	3/8 Inch	3/4 inch	RAP 1 (Fine)	RAP 2 (Coarse)				
Percent used in composite	35.0	13.0	8.0	19.0	15.0	10.0	Without Admix	With Admix *	Without Admix	With Admix
Sieve	Gradation – Percent Passing									
1”	100.0	100.0	100.0	100.0	100.0	100.0	100	100	100	100
3/4”	100.0	100.0	100.0	82.0	100.0	100.0	97	97	90 - 100	90 - 100
1/2”	100.0	100.0	100.0	13.6	100.0	63.0	80	80		
3/8”	100.0	100.0	100.0	4.0	100.0	10.5	73	73	62 - 77	62 - 77
1/4”	100.0	100.0	59.0	1.6	93.3	8.0	68	68		
#4	97.1	98.8	22.5	1.6	77.6	6.0	61	62		
#8	60.8	70.1	1.3	1.5	66.1	5.0	41	42	37 - 46	38 - 47
#10	58.8	68.1	1.2	1.5	43.6	4.5	37	37		
#16	33.3	45.1	1.0	1.5	40.3	4.0	24	25		
#30	19.4	31.3	1.0	1.5	31.4	3.5	16	17		
#40	13.9	25.9	0.9	1.4	23.7	3.0	12	13	10 - 18	11 - 19
#50	10.0	22.0	0.9	1.4	20.0	2.5	10	11		
#100	5.5	17.0	0.8	1.4	16.6	2.0	7	8		
#200	3.3	8.4	0.7	1.2	10.8	1.5	4.3	5.2	1.5 - 4.5	2.5 - 6.0

* 1.0 percent admixture, by weight of the total aggregate (virgin aggregate and RAP aggregate), is used in this example.

FIGURE 1

Example of Batch Sheet #1
(For Composite #1)
(Virgin Aggregate and RAP Aggregate)

MATERIAL	SIEVE	INDIV. % RET.	ACCUM. % RET.	FRACTURED COARSE AGGREGATE PARTICLES [Plus #4] (Virgin Agg. and RAP Agg.) (500 grams)	PERCENT CARBONATES [Plus #4] (Virgin Agg. and RAP Agg.) (300 grams)	ABRASION [Type B] (Virgin Agg.) (5000 grams)	ABRASION [Type B] (RAP Agg.) (5000 grams)
				ACCUMULATIVE WEIGHT (grams)			
Virgin Aggregate Washed Crusher Fines (35.0%)	#4	1.015	1.015	13	8	---	---
	#8	12.705	13.720	---	---	---	---
	- #8	21.280	35.000	---	---	---	---
Virgin Aggregate Crusher Fines (13.0%)	#4	0.156	35.156	15	9	---	---
	#8	3.731	38.887	---	---	---	---
	- #8	9.113	48.000	---	---	---	---
Virgin Aggregate 3/8 Inch (8.0%)	1/4”	3.280	51.280	57	34	---	---
	#4	2.920	54.200	95	57	---	---
	#8	1.696	55.896	---	---	---	---
	- #8	0.104	56.000	---	---	---	---
Virgin Aggregate 3/4 Inch (19.0%)	3/4”	3.420	59.420	139	83	---	---
	1/2”	12.996	72.416	306	184	2500	---
	3/8”	1.824	74.240	330	198	5000	---
	1/4”	0.456	74.696	336	201	---	---
	#8	0.019	74.715	---	---	---	---
	- #8	0.285	75.000	---	---	---	---
RAP Aggregate 1 (Fine RAP) (15.0%)	1/4”	1.005	76.005	349	209	---	---
	#4	2.355	78.360	379	227	---	---
	#8	1.725	80.085	---	---	---	---
	- #8	9.915	90.000	---	---	---	---
RAP Aggregate 2 (Coarse RAP) (10.0%)	1/2”	3.700	93.700	427	256	---	2500
	3/8”	5.250	98.950	494	297	---	5000
	1/4”	0.250	99.200	497	298	---	---
	#4	0.200	99.400	500	300	---	---
	#8	0.100	99.500	---	---	---	---
	- #8	0.500	100.000	---	---	---	---

FIGURE 2

17. ADJUSTED PERCENTAGE FOR EACH VIRGIN AGGREGATE STOCKPILE

17.1 In order to develop the data for Composite #2, Equations 18 and 19 are used to calculate the adjusted percentage for each virgin aggregate stockpile, as shown in Figure 3.

Equation 18: $P_{sv} = P_{sv1} + P_{sv2} + \ldots + P_{svn}$

Where: P_{sv} = Sum of the original individual virgin aggregate stockpile percentages from Composite #1.

P_{sv1}, P_{sv2}, P_{svn} = The original individual virgin aggregate stockpile percentages from Composite #1.

Example:

P_{sv1} = 35.0
P_{sv2} = 13.0
P_{sv3} = 8.0
P_{sv4} = 19.0

$P_{sv} = 35.0 + 13.0 + 8.0 + 19.0 = 75.0$

Equation 19: $P_{svcn} = \frac{P_{svn}}{P_{sv}} \times 100$

Where: P_{svcn} = Adjusted individual virgin aggregate stockpile percentages in Composite #2 (as a percentage of virgin aggregates only).

P_{svn} = The original individual virgin aggregate stockpile percentages from Composite #1.

P_{sv} = Sum of the original individual virgin aggregate stockpile percentages from Composite #1.

Example: (for Washed Crusher Fines)

P_{sv} = 75.0
P_{sv1} = 35.0

$$P_{svc1} = \frac{35.0}{75.0} \times 100 = 46.667$$

Example: (for Crusher Fines)

$$P_{sv} = 75.0$$
$$P_{sv2} = 13.0$$

$$P_{svc2} = \frac{13.0}{75.0} \text{ x } 100 = 17.333$$

Example: (for 3/8 Inch)

$$P_{sv} = 75.0$$
$$P_{sv3} = 8.0$$

$$P_{svc3} = \frac{8.0}{75.0} \text{ x } 100 = 10.677$$

Example: (for 3/4 Inch)

$$P_{sv} = 75.0$$
$$P_{sv4} = 19.0$$

$$P_{svc4} = \frac{19.0}{75.0} \text{ x } 100 = 25.333$$

Example of Composite #2
(Virgin Aggregate)

Material	Washed Crusher Fines	Crusher Fines	3/8 Inch	3/4 inch	Composite	
Original individual virgin aggregate stockpile percentages used in Composite #1.	35.0	13.0	8.0	19.0		
	(Total = 75.0%)					
Adjusted individual virgin aggregate stockpile percentages.	46.667	17.333	10.667	25.333	Without Admix	With Admix *
	(Total = 100%)					
Sieve	Gradation – Percent Passing					
1"	100.0	100.0	100.0	100.0	100	100
3/4"	100.0	100.0	100.0	82.0	95	95
1/2"	100.0	100.0	100.0	13.6	78	78
3/8"	100.0	100.0	100.0	4.0	76	76
1/4"	100.0	100.0	59.0	1.6	71	71
#4	97.1	98.8	22.5	1.6	65	65
#8	60.8	70.1	1.3	1.5	41	42
#10	58.8	68.1	1.2	1.5	40	41
#16	33.3	45.1	1.0	1.5	24	25
#30	19.4	31.3	1.0	1.5	15	16
#40	13.9	25.9	0.9	1.4	11	12
#50	10.0	22.0	0.9	1.4	9	10
#100	5.5	17.0	0.8	1.4	6	7
#200	3.3	8.4	0.7	1.2	3.4	4.7

* The weight of admixture used in the mix is based on the weight of the total aggregate (virgin aggregate and RAP aggregate). As shown in Composite #1, the percent admixture, by weight of the total aggregate, used in this example is 1.0 percent. However, since Composite #2 is for virgin aggregate only (but will contain all of the admixture), to correctly calculate the composite gradation with admixture the percent of admixture must be adjusted for the percent of RAP aggregate used in the mix (25.0% in this example). The adjusted percent of admixture is determined by dividing "100" by the percent of virgin aggregate (75.0 in this example). The resultant value (1.33 for this example) is the adjusted percent of admixture used to calculate the composite gradation with admixture.

$$\%\,\text{passing (with admix)} = \left[\frac{(\%\,\text{passing without admix}) + (\text{adjusted percent of admixture})}{100 + (\text{adjusted percent of admixture})}\right] \text{x}\,100$$

Example for the No. 200 sieve:

$$\%\,\text{passing (with admix)} = \left[\frac{3.4 + 1.33}{100 + 1.33}\right] \text{ x } 100 = 4.7$$

FIGURE 3

Example of Batch Sheet #2
(For Composite #2)
(Virgin Aggregate)

MATERIAL	SIEVE	INDIV. % RET.	ACCUM. % RET.	COARSE SPECIFIC GRAVITY [Plus #4] (4000 grams)	FINE SPECIFIC GRAVITY [Minus #4] (1200 grams)	SAND EQUIVALENT [Minus #4] (600 grams)	UNCOMPACTED VOID CONTENT [Minus #8] (500 grams)	MINUS NO. 8 MAKE-UP MATERIAL (500 grams)
				ACCUMULATIVE WEIGHT (grams)				
Virgin Aggregate Washed Crusher Fines (Adjusted = 46.667%)	#4	1.353	1.353	156	---	---	---	---
	#8	16.940	18.293	---	312	156	---	---
	- #8	28.374	46.667	---	833	417	346	346
Virgin Aggregate Crusher Fines (Adjusted = 17.333%)	#4	0.208	46.875	180	---	---	---	---
	#8	4.975	51.850	---	925	463	---	---
	- #8	12.150	64.000	---	1148	574	494	494
Virgin Aggregate 3/8 Inch (Adjusted = 10.667%)	1/4”	4.374	68.374	683	---	---	---	---
	#4	3.893	72.267	1131	---	---	---	---
	#8	2.261	74.528	---	1190	595	---	---
	- #8	0.139	74.667	---	1193	596	495	495
Virgin Aggregate 3/4 Inch (Adjusted = 25.333%)	3/4”	4.560	79.227	1656	---	---	---	---
	1/2”	17.328	96.555	3650	---	---	---	---
	3/8”	2.432	98.987	3930	---	---	---	---
	1/4	0.608	99.595	4000	---	---	---	---
	#8	0.025	99.620	---	---	---	---	---
	- #8	0.380	100.000	---	1200	600	500	500

FIGURE 4

18. ADJUSTED PERCENTAGE FOR EACH RAP STOCKPILE

18.1 In order to develop the data for Composite #3, Equation 20 is used to calculate the adjusted percentage for each RAP stockpile, as shown in Figure 5.

Equation 20: $$P_{rcn} = \frac{P_{ran}}{1 - \frac{P_{brn}}{100}}$$

Where: P_{rcn} = Adjusted individual RAP stockpile percentages (includes RAP binder).

P_{ran} = Percent of each RAP aggregate used (Determined from Composite #1).

P_{brn} = Binder content of the material from each RAP stockpile.

Example: For RAP Stockpile 1 (Fine RAP)

P_{ra1} = 15.0
P_{br1} = 5.82

$$P_{rc1} = \frac{15.0}{1 - \frac{5.82}{100}} = 15.927$$

Example: For RAP Stockpile 2 (Coarse RAP)

P_{ra2} = 10.0
P_{br2} = 3.43

$$P_{rc2} = \frac{10.0}{1 - \frac{3.43}{100}} = 10.355$$

Example of Composite #3
(Virgin Aggregate and Dry Screened RAP)

Material	Virgin Aggregate (75.0%)				Dry Screened RAP (26.282%)		Composite Without Admix **
	Washed Crusher Fines	Crusher Fines	3/8 Inch	3/4 inch	RAP 1 (Fine) (% Binder = = 5.82) *	RAP 2 (Coarse) (% Binder = 3.43) *	
Percent used in composite	35.0	13.0	8.0	19.0	15.927	10.355	Total = 101.282
Sieve	Gradation - Percent Passing						
1”	100.0	100.0	100.0	100.0	100.0	100.0	101
3/4”	100.0	100.0	100.0	82.0	100.0	94.4	97
1/2”	100.0	100.0	100.0	13.6	100.0	57.1	80
3/8”	100.0	100.0	100.0	4.0	100.0	13.7	74
1/4”	100.0	100.0	59.0	1.6	68.1	8.0	65
#4	97.1	98.8	22.5	1.6	54.5	4.9	58
#8	60.8	70.1	1.3	1.5	24.8	2.2	35

* By weight of Dry Screened RAP

** The composite gradation without admixture includes the contribution of binder in the Dry Screened RAP [as indicated by the total percent of Dry Screened RAP (26.282%), the total percent of Virgin Aggregate and Dry Screened RAP used in the composite (101.282%), and the percent passing the 1 inch sieve (101%)].

FIGURE 5

Example of Batch Sheet #3
(For Composite #3)
(Virgin Aggregate and Dry Screened RAP)

MATERIAL	SIEVE	INDIVIDUAL PERCENT RETAINED	ACCUMULATIVE PERCENT RETAINED	RICE (3000 grams) [1]	MARSHALL (3300 grams) [1]	IMC (3400 grams) [1]	RICE (3150 grams from each Dry Screened RAP stockpile): Accumulative Percent Retained	RICE (3150 grams from each Dry Screened RAP stockpile): Accumulative Percent Retained (Adjusted to 100%)	RICE (3150 grams from each Dry Screened RAP stockpile): Accumulative Weight (grams) [4]
				ACCUMULATIVE WEIGHT (grams) [2] and [3]					
VIRGIN AGGREGATE (75.0%)									
Washed Crusher Fines (35.0%)	#4	1.015	1.015	30	33	35			
	#8	12.705	13.720	412	453	466			
	- #8	21.280	35.000	1050	1155	1190			
Crusher Fines (13.0%)	#4	0.156	35.156	1055	1160	1195			
	#8	3.731	38.887	1167	1283	1322			
	- #8	9.113	48.000	1440	1584	1632			
3/8 Inch (8.0%)	1/4"	3.280	51.280	1538	1692	1744			
	#4	2.920	54.200	1626	1789	1843			
	#8	1.696	55.896	1677	1845	1900			
	- #8	0.104	56.000	1680	1848	1904			
3/4 Inch (19.0%)	3/4"	3.420	59.420	1783	1961	2020			
	1/2"	12.996	72.416	2172	2390	2462			
	3/8"	1.824	74.240	2227	2450	2524			
	1/4"	0.456	74.696	2241	2465	2540			
	#8	0.019	74.715	---	2466	---			
	- #8	0.285	75.000	2250	2475	2550			
Weight of Mineral Admixture (Type IP Cement) [1.0%, by weight of Virgin Aggregate and RAP Aggregate]				30	33	34			
Total weight of Virgin Aggregate and Mineral Admixture				2280	2508	2584			
DRY SCREENED RAP (26.282%)									
RAP 1 (Fine) (15.927%)	1/4"	5.081	5.081	152	168	173	5.081	31.902	1005
	#4	2.166	7.247	217	239	246	7.247	45.501	1433
	#8	4.730	11.977	359	395	407	11.977	75.199	2369
	- #8	3.950	15.927	478	526	542	15.927	100.000	3150
RAP 2 (Coarse) (10.355%)	3/4"	0.580	16.507	495	545	561	0.580	5.601	176
	1/2"	3.862	20.369	611	672	693	4.442	42.897	1351
	3/8"	4.494	24.863	746	820	845	8.936	86.296	2718
	1/4"	0.590	25.453	764	840	865	9.526	91.994	2898
	#4	0.321	25.774	773	851	876	9.847	95.094	2995
	#8	0.280	26.054	782	860	886	10.127	97.798	3081
	- #8	0.228	26.282	788	867	894	10.355	100.000	3150
Total weight of Virgin Aggregate and Dry Screened RAP				3038	3342	3444			
Total weight of Virgin Aggregate, Dry Screened RAP, and Mineral Admixture				3068	3375	3478			

[1] Desired Weight of Virgin Aggregate and RAP Aggregate.

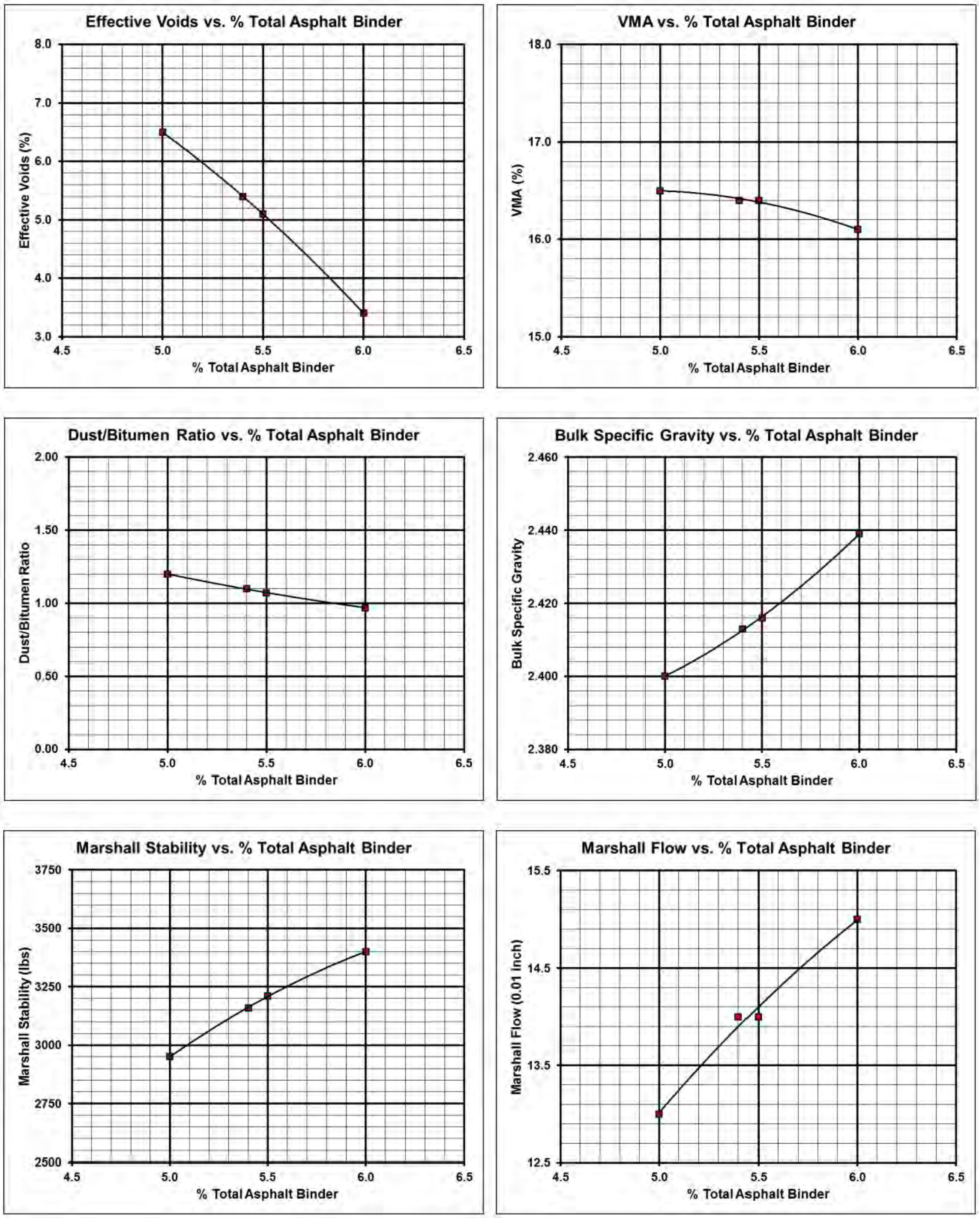
$$[2]\quad \left[\begin{array}{l}\text{Accumulative Wt.}\\ \text{for each sieve}\\ \text{(Virgin Agg.)}\end{array}\right] = \left(\begin{array}{l}\text{Desired Weight}\\ \text{of Virgin Agg.}\\ \text{and RAP Agg.}\end{array}\right) \times \left(\frac{\begin{array}{c}\text{Accumlative \% Retained for}\\ \text{each sieve (Virgin Agg.)}\end{array}}{100}\right)$$

$$[3]\quad \left[\begin{array}{l}\text{Accumulative Wt.}\\ \text{for each sieve}\\ \text{(Dry Screened RAP)}\end{array}\right] = \left(\begin{array}{l}\text{Desired Weight}\\ \text{of Virgin Agg.}\\ \text{and RAP Agg.}\end{array}\right) \times \left(\frac{\begin{array}{c}\text{Accumlative \% Retained for}\\ \text{each sieve (Dry Screened RAP)}\end{array}}{100}\right)$$

$$[4]\quad \left[\begin{array}{l}\text{Accumulative Wt. for each sieve}\\ \text{for Rice from each Dry}\\ \text{Screened RAP Stockpile}\end{array}\right] = \left(\begin{array}{l}\text{Accumulative \% Retained (Adjusted}\\ \text{to 100\%) for each sieve from each}\\ \text{Dry Screened RAP Stockpile}\end{array}\right) \times 3000$$

FIGURE 6

Example Plots of Effective Voids, VMA, Dust/Bitumen Ratio, Bulk Specific Gravity, Marshall Stability, and Marshall Flow versus Percent Total Asphalt Binder Content



The above graphs are for illustrative purposes only. Straight-line interpolation, as specified in Subsections 13.3 and 13.3.1, is used for mix design calculations.

FIGURE 7

Asphaltic Concrete Marshall Mix Design with RAP
Example Mix Design Summary (Page 1 of 2)

Contractor: Best Paving Contractors, Inc.	**Date:** February 22, 2013
ADOT Project Number: STP-999-Z(999)A	**Mix Design Laboratory:** XYZ Testing Laboratories
ADOT TRACS Number: H999901C	**Mix Design Engineer:** Raul "RAP MAN" Raponi
Project Name: Nowhere - Somewhere	**Asphalt Binder Specified in Special Provisions:** PG 76-16
Mix Designation: ADOT 416 (3/4 Inch Special Mix with RAP)	**Virgin Asphalt Binder Required by Mix Design:** PG 76-22

COMPOSITE GRADATION:

Virgin Aggregate (75.0%)	Percent Used
Washed Crusher Fines	35.0
Crusher Fines	13.0
3/8 Inch	8.0
3/4 Inch	19.0
RAP Aggregate (25.0 %)	
RAP 1 (Fine)	15.0
RAP 2 (Coarse)	10.0
Mineral Admixture (1.0%)	
Type IP Cement	1.0

Sieve Size	Percent Passing w/o Admix	Percent Passing w/ Admix	Specifications	
			Without Admix	With Admix
1"	100	100	100	100
3/4"	97	97	90 - 100	90 - 100
1/2"	80	80		
3/8"	73	73	62 - 77	62 - 77
1/4"	68	68		
#4	61	62		
#8	41	42	37 - 46	38 - 47
#10	37	37		
#16	24	25		
#30	16	17		
#40	12	13	10 - 18	11 - 19
#50	10	11		
#100	7	8		
#200	4.3	5.2	1.5 – 4.5	2.5 – 6.0

DESIGN DATA:

% Total Binder	5.0	**5.4**	5.5	6.0	Spec.
Bulk Specific Gravity	2.400	**2.413**	2.416	2.439	
Bulk Density (lb./cu. ft)	149.5	**150.3**	150.5	151.9	
Stability (lb.)	2950	**3160**	3210	3400	2000 Min.
Flow (0.01 inch)	13	**14**	14	15	8 - 16
Effective Voids (%)	6.5	**5.4**	5.1	3.4	5.3 – 5.7
VMA (%)	16.5	**16.4**	16.4	16.1	15.0 – 18.0
Effective Asphalt, Total Mix (%)	4.34	**4.74**	4.84	5.34	
Dust/Bitumen Ratio	1.20	**1.10**	1.07	0.97	0.6 – 1.2
Absorbed Asphalt (%)	0.70				0 – 1.0
Max. Theoretical Specific Gravity at 5.4% Total Binder = 2.550					
Max. Theoretical Density at 5.4% Total Binder = 158.9 lb/cu. ft.					

RECOMMENDED TOTAL BINDER CONTENT:	**5.40%***
ADDED VIRGIN BINDER CONTENT:	**4.20%***
CONTRIBUTED RAP BINDER CONTENT:	**1.20%***
*By weight of total mix	

PERCENT RAP BINDER (Equation 7)**:**	**22.24%***
PERCENT VIRGIN BINDER (100 - % RAP Binder)**:**	**77.76%***
*By weight of total binder in the mix	

IMMERSION COMPRESSION – ARIZ 802: 5.4% Total Binder, 1.0% Type IP Cement		Spec.
Dry Strength (psi)	269	-----
Wet Strength (psi)	197	150 Min.
Index of Retained Strength (%)	73	60 Min.

PERCENT RAP AGGREGATE:	**25.0%***
PERCENT VIRGIN AGGREGATE:	**75.0%***
*By weight of total aggregate in the mix	

RAP 1 (FINE) PERCENT RAP BINDER:	5.82%
RAP 2 (COARSE) PERCENT RAP BINDER:	3.43%

RAP 1 (FINE) RAP BINDER GRADE (ACTUAL):	93-8
RAP 2 (COARSE) RAP BINDER GRADE (ACTUAL):	91-9

RAP 1 (FINE) RAP BINDER SPECIFIC GRAVITY:	1.049 @ 77°F
RAP 2 (COARSE) RAP BINDER SPECIFIC GRAVITY:	1.052 @ 77°F

AGGREGATE PROPERTIES: (See page 2.)

ADDITIONAL DATA / INFORMATION:
Source of RAP: Existing Project Roadway
Source of Virgin Aggregate: Excellent Aggregate Materials, Inc.
Source of Virgin Asphalt Binder: Supreme Asphalt Suppliers, Inc.
Source of Mineral Admixture: Superior Hydraulic Cements, Inc.
Virgin Asphalt Binder Type/Specific Gravity: PG 76-22/1.026 @ 77°F
Mineral Admixture Type/Specific Gravity: Type IP Cement/3.00
Blended Virgin Binder and RAP Binder Grade: PG 76-16
Blended Virgin Binder and RAP Binder Specific Gravity: 1.031 @ 77°F
Laboratory Mixing Temperature Range: 304 °F to 314 °F
Laboratory Compaction Temperature Range: 286 °F to 293 °F
Actual Laboratory Mixing Temperature Used: 309 °F
Actual Laboratory Compaction Temperature Used: 290 °F

REMARKS:

FIGURE 8 (Continued on Next Page)

Asphaltic Concrete Marshall Mix Design with RAP
Example Mix Design Summary (Page 2 of 2)

AGGREGATE PROPERTIES:

Test Characteristic	Virgin Aggregate				RAP Aggregate				Combined Virgin Aggregate and RAP Aggregate		
	Fine	Coarse	Combined	Spec.	RAP 1 (Fine)	RAP 2 (Coarse)	Combined	Spec.	Without Admixture.	With Admixture.	Spec.
Bulk OD Specific Gravity	2.797	2.789	2.794	2.350 - 2.850	2.660	2.403	---	---	---	2.732	---
SSD Specific Gravity	2.828	2.821	2.826	---	2.690	2.430	---	---	---	2.762	---
Apparent Specific Gravity	2.887	2.883	2.885	---	2.742	2.470	---	---	---	2.818	---
Absorption	1.11	1.17	1.13	0 -2.5%	1.13		---	---	---	1.13	---
Effective Specific Gravity	---	---	---	---	2.694	2.431	---	---	---	2.784	---
Sand Equivalent	76			55 Min.	---	---	---	---	---	---	---
Uncompacted Void Content	48.6			45.0 Min.	---	---	---	---	---	---	---
Carbonates	---	---	---	---	---	---	---	---	4	---	20% Max.
Fractured Coarse Aggregate Particles											
At least one fractured face	---	---	---	---	---	---	---	---	98	---	92% Min
At least two fractured faces	---	---	---	---	---	---	---	---	97	---	85% Min.
Abrasion	(Type B)				(Type B)						
100 Rev., % loss	3			9 Max.	5			9 Max.	---	---	---
500 Rev., % loss	14			40 Max.	28			40 Max.	---	---	---

FIGURE 8 (Continued from Previous Page)