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:

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

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

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

Equation 4:

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

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

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

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

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	---

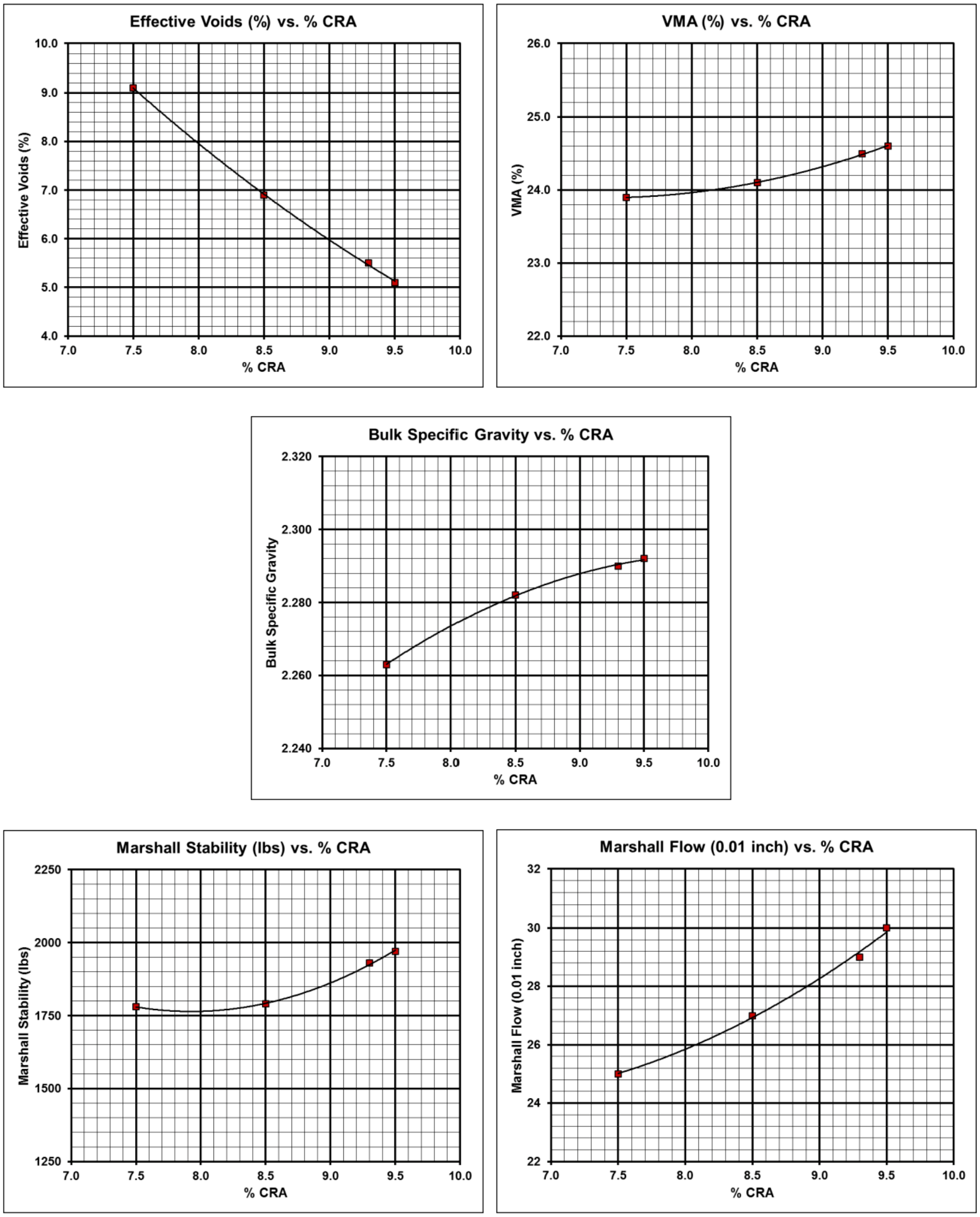
FIGURE 2

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.	**Mix Designation:** ADOT 415 [Asphaltic Concrete (Asphalt-
ADOT Project Number: STP-777-Z(777)A	**Mix Design Laboratory:** XYZ Testing Laboratories
ADOT TRACS Number: H777701C	**Mix Design Engineer:** Frank Dogood
Project Name: Uptown - Downtown	**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	Specifications 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)