ARIZ 815d
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(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:

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:

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

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. 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:

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

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

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

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

Equation 4:

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

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:

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

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

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

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

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

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

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

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 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	---

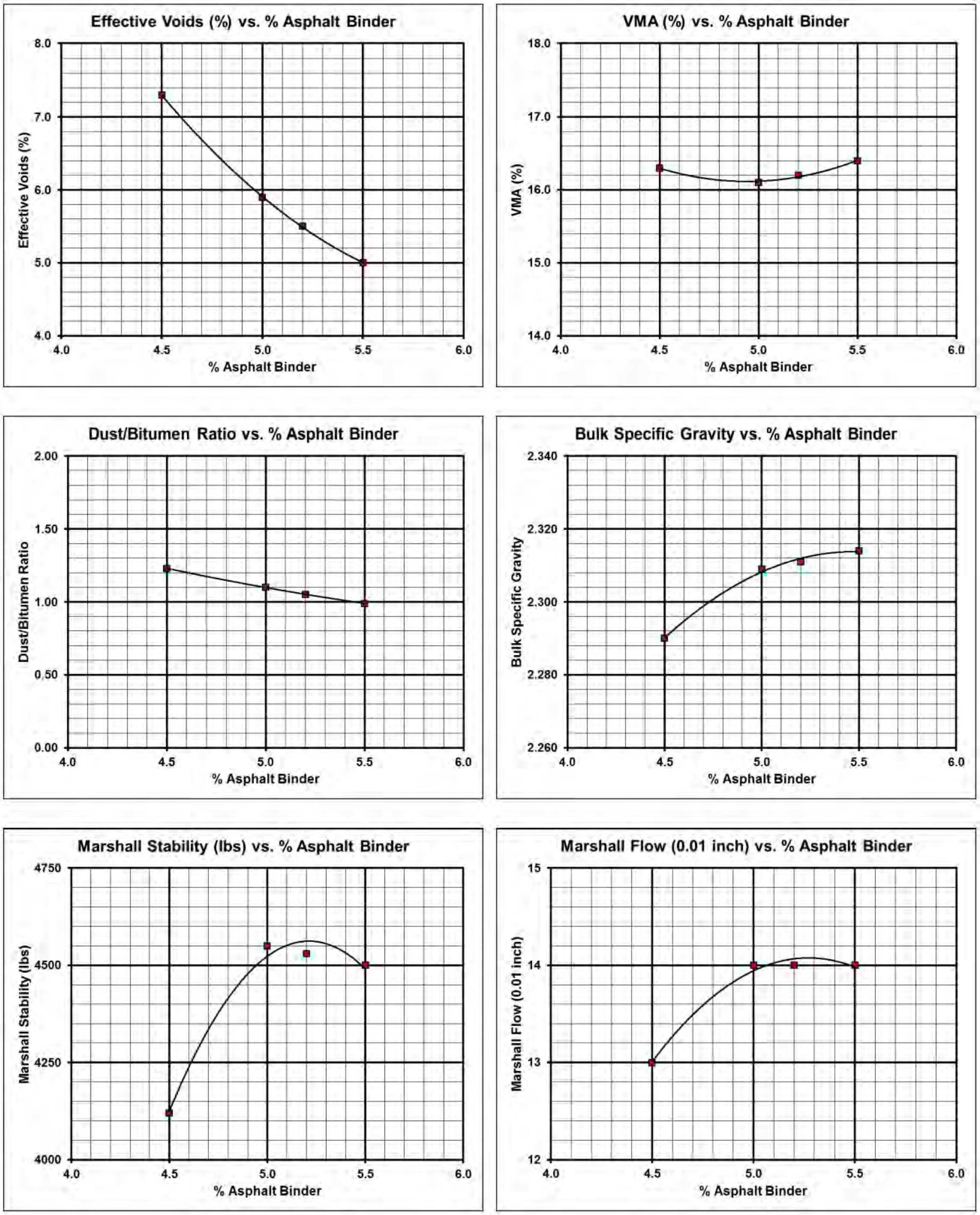
FIGURE 2

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	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.

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

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.

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