April 16, 2013 Matls. IM 510
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METHOD OF DESIGN OF ASPHALT MIXTURES

SCOPE

The design of asphalt mixtures involves determining an economical blend of aggregates that provides a combined gradation within the limits of the specifications and a determination of the percent of asphalt binder to mix with the aggregate blend, which provides a mix, which meets volumetric specifications. Trial mixes prepared with different binder contents are tested for mix properties and the results are analyzed to select the binder content that is judged to be most satisfactory for the intended use of the mix.

This IM will cover the sample preparation procedure, aggregate blend selection, binder content selection and the evaluation of the test results. Individual test method IMs are referenced for measuring the properties of individual mixes.

> **NOTE:** The aggregate variable and asphalt binder variable blends are important tools needed by the production control technician for field adjustment of the Job Mix Formula (JMF).

Appendix A of this IM contains the criteria for Gyratory mix design.

REFERENCED DOCUMENTS:

Standard Specification 4127 Type A & B Aggregate for Hot Mix Asphalt
AASHTO R-35 Practice for Superpave Volumetric Design for Hot Mix Asphalt (HMA)
AASHTO R 30, Standard Practice for Mixture Conditioning of Hot-Mix Asphalt (HMA)
IM 302 Sieve Analysis of Aggregates
IM 306 Determining the Amount of Material Finer than the #200 (75 µm) Sieve in Aggregate
IM 336 Reducing Aggregate Field Samples to Test Samples
IM 321 Compacted Density of Hot Mix Asphalt (HMA)(Displacement)
IM 319 Moisture Sensitivity Testing of Asphalt Mixtures
IM 325G Determining the Density of Hot Mix Asphalt (HMA) Using the Superpave Gyratory Compactor (SGC)
IM 350 Determining Maximum Specific Gravity of Hot Mix Asphalt (HMA) Mixtures
IM 357 Preparation of Hot Mix Asphalt (HMA) Mix Samples for Test Specimens
IM 369 Determining Specific Gravity of Asphalt Binder
IM 380 Vacuum-Saturated Specific Gravity & Absorption of Combined or Individual Aggregate Sources
IM 501 Asphaltic Terminology, Equations & Example Calculations
IM 511 Control of Hot Mix Asphalt Mixtures

APPARATUS

- Thermometers: Armored-glass, dial type or digital thermometer with metal stems is recommended. A range of 50° to 400°F (10° to 200°C) with graduations of 5°F (2°C) is required.

- Balances: 20,000-gram capacity, 0.1 gram resolution for mix design and production testing.

- Forced Draft Oven, 350°F (177°C) minimum with controls sensitive to ± 5°F (3°C), minimum size, 7 cu. ft. for production testing or mix design.

> **NOTE:** Experience has shown that a 15 cu. ft. or larger oven may be desirable.

- Mixer: Hobart 19 liters with Dough Hook, Model A-200 for Mix Design.

- Safety equipment: insulated gloves, long sleeves, apron, etc.

- Pans of sufficient size for splitting and curing of samples.

General Equipment:

- Scoop or trowel for moving mixture.

PROCEDURE

A. MATERIALS SELECTION

The aggregate source properties shall comply with Standard Specification 4127.

The Contractor selects the aggregate and Recycled Asphalt Materials (RAM) sources and the types and source of asphalt binder. Aggregate sources and types, individual gradations, crushed particle amount, aggregate friction type, binder grade, and other specific requirements should be checked prior to submitting materials and Form #820955 to the laboratory. The gradation of the combined aggregate submitted for trial mix testing shall meet the requirements of the Project Plans and Specifications.

The Contractor must notify the District Materials Engineer prior to sampling of the aggregate stockpiles and RAM. The Contractor should estimate, in cooperation with the producers, the tentative proportions and gradations of each of the materials. A stockpile of at least 500 tons (500 Mg), or project amount if less must be produced so that representative samples of the processed material can be obtained. The target gradation, for each source, to be reported on Form #820955 is the average gradation for the stockpile as determined by using the Quality Control and Monitor samples. Enter the target gradation for each source into the SHADES Mix Design program.

Representative RAM samples shall be sent into the laboratory designated by the Engineer for material classification (for State work this is the Central Materials Laboratory). The laboratory will report the results of the tests within 15 working days. The following information will be provided for RAP: Fine Aggregate Angularity, Extracted P_b, gradation, and specific gravity of aggregate. The % friction aggregate, % crushed, and types of aggregate will be provided if available. Extracted binder content of RAS samples will be provided.

For mixtures not containing RAS, when the amount of recycled binder from RAP exceeds 20.0% of the total asphalt binder, the designated binder grade will drop one step. (If a PG 64-22 was originally specified, PG 58-28 shall be used). If the anticipated RAM binder percent exceeds 30% of the total, the selection of the binder grade shall be based on testing performed by the Contracting Authority.

For mixtures containing RAS, adjust the contract binder grade as follows:

a. When the amount of recycled binder is inclusively between 15.0% and 25.0%
  1) Lower the high temperature grade of the virgin asphalt binder by one grade.
  2) Lower the low temperature grade of the virgin asphalt binder by one grade (i.e. PG XX-28 becomes PG XX-34).

b. When the amount of recycled binder exceeds 25.0% of the total asphalt binder, the binder grade shall be selected based on fracture energy as measured by the Disk-Shaped Compact Tension Test (DCT) (ASTM D7313-07a) at no additional cost to the contracting authority. Meet the following minimum fracture energy requirements tested at 10°C warmer than the low temperature PG Grade.
- >30M ESALS 690 J/m^2
- 10-30M ESALS 460 J/m^2
- <10M ESALS 400 J/m^2

The temperature spread of the adjusted PG grade shall be at least that of the contract grade (i.e. for a PG 64-22, maintain a spread of at least 64 – (-22) = 86). The adjusted grade shall meet the same elastic recovery requirements as the contract binder grade. No adjustments will be made to the contract unit price for required changes to the asphalt binder grade.

Warm Mix Asphalt (WMA)

1. WMA Process Selection

a) **WMA Technology**

Select the WMA process that will be used in consultation with the specifying agency and technical assistance personnel from the WMA suppliers. Consideration should be given to a number of factors including: (1) available performance data, (2) the cost of the warm mix additives, (3) planned production and compaction temperatures, (4) planned production rates, (5) plant capabilities, and (6) modifications required to successfully use the WMA process with available field and laboratory equipment.

b) **WMA Temperatures**

Determine the temperatures that will be used for plant mixing (production) and field compaction. Binder grade selection depends on the plant production temperature. See Table 1 for production temperatures below which the high temperature grade of the binder should be increased one level.

2. Binder Grade Selection for WMA

Increase the high temperature performance grade based on the proposed production temperature. Increase the high temperature performance grade by one grade when the plant discharge temperature is less than that specified in Table 1.

RAM: If more than 20% but less than 30% of the total binder contribution is from a recycled source, the designated high temperature binder grade will remain unchanged if the production temperature falls below that indicated in Table 1.

Table 1 - Production Temperatures below which the High Temperature Grade Should be Increased One Grade.

Specified PG High Temperature Grade	Aging Index (AI)[1]											
	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6
	Minimum WMA Mixing Temperature Not Requiring PG Grade Increase, °F											
52	<215	<215	<215	<215	<215	<215	220	220	225	225	230	230
58	<215	<215	<215	220	225	230	235	235	240	240	245	245
64	<215	<215	220	230	235	235	240	245	245	250	250	250
70	<215	220	230	240	245	245	250	255	255	260	260	260

Note: [1.] $AI = \frac{(G^*/\sin\delta)_{RTFOT}}{(G^*/\sin\delta)_{Tank}}$ at the high temperature performance grade temperature.

3. WMA Additives

Use additives as required by the proposed WMA process or to obtain acceptable coating, workability, compactibility, and moisture susceptibility.

B. JOB MIX FORMULA (JMF)

The JMF together with the specifications provides the initial basis for setting up and starting the job.

To avoid possible delays in the approval of the JMF, the District Materials Engineer should be notified that the Contractor is preparing a JMF. The District Materials Engineer will normally review the complete trial JMF within five working days. The District Materials Engineer may approve a laboratory mix design outside of the gradation control points, provided the plant produced mixture meets the specifications in all respects. It is expected that this would be considered only when the anticipated aggregate gradation is expected to result in a plant produced mixture within specifications.

C. MATERIAL PREPARATION

Approximately 250 lbs. (114 kilograms) of the combined aggregate will normally be required for the design work. If aggregate variable blends are to be tested prior to the asphalt variable design work, approximately 500 lbs. (228 kilograms) of aggregate may be necessary. This will allow enough material for the following:

1. Four mix samples of a minimum 13,000-gram batch.

> **NOTE:** If a 2nd Rice sample is desired, a minimum of 14,000 grams is recommended.

2. One sample of each individual aggregate for vacuum saturated specific gravity and absorption (IM 380).

3. Approximately 50 lbs. (23 kilograms) of material will be used for mix design verification when required.

To prepare the aggregate and RAM samples the following steps should be followed:

4. Obtain samples of each individual source material by following the procedure in IM 336. Perform a sieve analysis on each of the individual materials according to IM 302 and IM 306. Weigh the retained and passing portions of the aggregate, and calculate the percent retained on each sieve split by the following equation:

$$Z = \frac{X}{X + Y} \times 100$$

Where: "X" = weight of the retained portion, g
"Y" = weight of the passing portion, g
"Z" = percent of the total sample retained

5. Aggregates and RAM must be air dried to a surface dried condition prior to further preparation.

6. Review aggregate gradations as indicated on Form# 820955. If the gradation result, for each individual aggregate, found in Step C.4 is within the production tolerance of the gradation indicated on Form #820955, an initial split is made by sieving on the screen size that will most nearly result in a 50-50 percent split. When the screen size selected for the initial split is coarser than the #4 sieve, additional splits shall be made on all sieves down to and including the #4 which retain at least 10% of the material. If the gradation result is outside the production tolerance of the gradation indicated on Form #820955, sieving on each sieve size down to an including the #8 sieve is performed. All sieving must be done to completion.

NOTE: Sieving on each sieve size down to and including the #8 sieve is always an option even if the gradation results found in Step C.4 are within the production tolerances.

7. In no case shall any sample or sample portion be split on a #16 or smaller size sieve.

8. After sample splitting is complete, dry the individual portions of the aggregate for a minimum of 6 hours in an oven at a temperature of 275° ± 10°F (135° ± 6°C) for HMA mixtures, or until the aggregates reach a constant weight when weighed at 30 minute intervals. Use 60°F (15°C) above the proposed production temperature for WMA mixtures.

   NOTE: RAM is not oven-dried.

9. When a mix designer suspects that the coarse aggregate portion contains excessive fines (dust coatings or clumps), an amount of correction should be established. The procedure used to determine the amount of correction required is found in Appendix B of this IM.

10. Prior to aggregate blend selection, the aggregate source properties, the bulk dry specific gravity and absorption of the individual aggregate samples as well as the specific gravity of the binder at 77°F (25°C) must be determined. In addition, the consensus properties of the individual aggregates may be determined to estimate the combined aggregate properties. Properties of RAM sources are as provided by the Contracting Authority.

NOTE: G_b at 77°F (25°C) may be obtained from certifying documents or test reports (IM 369). Certifying documents may report G_b at 60°F (15°C).

D. AGGREGATE BLEND SELECTION

This section explains the selection of an aggregate blend determined to be the most appropriate blend that will meet the design criteria. The mix designer may establish an aggregate blend based on past experience or by evaluating multiple blends. The shape of the gradation plotted on the 0.45 power gradation chart generally reflects the void space available for asphalt. Gradations that closely follow the maximum density line generally have minimal void space.

1. Select a minimum of three blends, which cover a broad range of aggregate properties (shape, texture, gradation, etc…).

2. Check the aggregate consensus properties of each blend as specified in Appendix A.

3. Select a trial asphalt binder content for each of the proposed blends by one of the five methods below. The asphalt binder used for trial mixes shall be of the same grade as indicated on Form #820955 and shall be from the same source when possible.

   a. Experience
   b. SHADES Mix Design Program
   c. AASHTO R-35
   d. Calculated surface area of the aggregate (See Note.)

   > **NOTE:** The asphalt film thickness obtained at a given binder content is related to the surface area and asphalt absorption of the aggregate. A higher surface area will generally, but not always, require a higher binder content.

   e. The following table showing statewide averages

BASIC ASPHALT BINDER CONTENT, PERCENT

Mixture Size	Aggr. Type	1 inch	3/4 inch	1/2 inch	3/8 inch
Intermediate and Surface	A	4.75	5.50	6.00	6.00
Intermediate and Surface	B	5.25	5.75	6.00	6.25
Base	B	5.25	6.00	6.00	6.25

4. Check that the trial asphalt binder content selected for each aggregate blend could meet the film thickness and F/B ratio criteria as specified in Appendix A.

5. Use the procedure in the “Mixture Batching, Curing & Testing” section to batch, cure and test trial blends.

6. Evaluate the mixture properties of each trial blend as specified in Appendix A.

Mixes that meet the design criteria may proceed to asphalt binder variable design. Aggregate blend selection should take into consideration the source availability, ability to adjust field production and source cost.

E. ASPHALT BINDER CONTENT SELECTION

Trial mixes are prepared at a minimum of three different asphalt binder contents to assure close bracketing of the final recommended design binder content. Trial binder contents shall cover a minimum range of 1.0%. The final recommended binder content must be bracketed by trial binder contents within 1.0% above and below. Contractor prepared mix designs may require a mixture prepared at the recommended design binder content for DOT mix design verification.

> **NOTE:** If a four-point design is desired, the trial binder contents shall cover a minimum range of 1.5%.

Select an initial trial asphalt binder content by one of the five methods below. The binder used for trial mixes shall be of the same grade as indicated on Form #820955 and shall be from the same source when possible.

a. Experience
b. SHADES Mix Design Program
c. AASHTO R-35
d. Calculated surface area of the aggregate (See Note.)

> **NOTE:** The asphalt film thickness obtained at a given binder content is related to the surface area and asphalt absorption of the aggregate. A higher surface area will generally, but not always, require a higher binder content.

e. The basic asphalt binder content table from Step D.3

> **NOTE:** To avoid wasted effort in the laboratory when using unfamiliar materials, the mix designer is encouraged to perform a single point analysis of the volumetric properties prior to performing the complete (multi point or bracketing) analysis. For the purposes of adjusting the trial binder content to the proper void level, the following general rule applies: A 0.2% change in asphalt binder content is approximately a 0.5% change in air voids.

Anti-stripping Agents

See Article 2303.02, E, 2, h for allowed use. For HMA designs which use a liquid anti-stripping agent, if the agent also acts as a compaction aid then after the optimum binder content has been selected, compact an additional specimen (with binder that has been dosed with the agent) to ensure the target air void content is met. If air voids have changed by more than 0.5% then adjust the binder content accordingly to achieve target voids prior to production.

F. MIXTURE BATCHING, CURING & TESTING

The following procedures should be used for the batching, curing and testing of mixes. These procedures are to be used for both the “aggregate blend selection” and “asphalt binder content selection” phases of mix design. For WMA mixtures not utilizing a water-injection system, the WMA technology should be used in fabricating specimens in the mixture design phase. Methods for WMA specimen preparation are process specific. Consult the manufacturer for detailed WMA specimen fabrication procedures

1. Accurately batch the aggregates in the correct proportions to obtain the desired batch weight. The desired amount of RAM plus an additional 100 grams, to compensate for moisture loss, will be weighed in a separate pan. The individual aggregate split sample batch weight is determined by the following equation:

   Split sample aggregate batch weight = (A)(B)(C)

Where: A = total aggregate batch weight desired
B = individual aggregate in total aggregate batch weight, %
C = split portion of individual aggregate, %

NOTE: If RAM is included in the mix, the aggregate proportions must be adjusted for the purpose of determining the combined aggregate gradation and combined specific gravity. Use the formulas in IM 501.

2. Determine the amount of asphalt binder needed for each trial mix batch as follows:

$$\text{Binder Weight} = \frac{(\text{aggregate batch weight}) \times (\text{Target } P_b)}{(100 - \text{Target } P_b)}$$

NOTE: If RAM is included in the mix, the $P_{b\ (added)}$ content must be determined. Use the formulas in IM 501.

3. For HMA mixtures, separately heat the combined aggregate batch and binder to 275° ± 5°F (135° ± 3°C) as checked by a thermometer in the pan of aggregate. For WMA mixtures, heat the combined aggregate batch and binder containing the WMA technology (at the dosage recommended by the manufacturer) to the proposed production temperature ± 5°F (± 3°C). The mixing bowl and utensils shall also be heated before mixing operations begin. Always keep the mixing bowl buttered.

NOTE: It generally takes 4 hours to bring aggregates & binder to mixing temperature. RAM will be heated in a separate pan for a maximum of 2 hours to minimize binder aging.

4. Weigh the required amount of RAM into the mixing bowl; pour the heated aggregate into the bowl and dry mix for 15 seconds on speed 1. Stop mixer.

5. Add the required amount of binder and mix for 15 seconds on speed 1. Stop mixer, shift to speed 2 and continue to mix for 45 seconds. Stop mixer.

6. Lower the mixing bowl and clean the dough hook and the bottom and side of the bowl by scraping with a spatula. Incorporate any adhering mixture or binder back into the sample within 2 minutes from the start of the cleaning operation.

7. Raise the bowl and continue mixing for 15 seconds on speed 2. Then repeat Step F.6 and again stir any adhering mix or binder back into the sample with the spatula.

8. Break the samples down according to IM 357.

   a. Take 2 samples of approximately 5000 gram each for gyratory compaction.

   b. Take a sample of a minimum of 2000 gram for G_{mm} determination.

9. Spread the material into a pan such that the material is 1 to 2 in. (25 to 50 mm) thick.

10. For HMA mixtures, cure all samples for 2 hours at 275°F (135°C). For WMA mixtures, cure all samples for 2 hours at the proposed field compaction temperature. 1 hour into curing, all samples are removed, thoroughly stirred and placed back into the oven for remainder of curing time.

11. Place approximately 4800 grams of material into the mold for gyratory specimens. Compact HMA specimens at 275°F (135°C) and WMA specimens at the proposed field compaction temperature per IM 325G.

    a. If necessary, adjust the weight of the sample to achieve the required test specimen height.

$$\text{Adjusted sample weight} = \frac{(\text{trial sample weight})(\text{intended height})}{\text{trial sample height}}$$

    b. Adjust the weight of the sample 1.25% for every 1% change in binder content.

12. Test loose mix at each binder content for maximum specific gravity per IM 350.

13. Measure the density (G_{mb}) of the compacted specimens per IM 321.

G. MIXTURE PERFORMANCE EVALUATION

A binder content is selected that will produce percent air voids in the compacted specimens equal to the target air void value. The test data and calculated results at the selected binder content are compared to the criteria specified in Appendix A. Interpolation may be necessary. Mixture designs may also be tested using IM 319 when required by the specifications.

DOCUMENTATION

A copy of the SHADES computer file containing all the test data must be submitted to the DME for approval of the JMF. For WMA mixture designs, report proposed production temperature, compaction temperature, WMA technology, additional equipment requirements from the manufacturer, manufacturer name, proposed dosage rate, and any manufacturer recommendations on Form #820956. The signed individual materials report (Form #820955) and JMF report (Form #820956) (including economic justification when required) are required prior to starting the paving.

Distribution of the documents:

District Materials Engineer
Project Engineer
Contractor
Central Materials Office