Kentucky Method 64-427-05
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METHOD FOR DESIGNING ASPHALT MIXTURES CONTAINING RECYCLED-ASPHALT PAVEMENT (RAP)

1. SCOPE AND RELATED METHODS:

1.1. This method covers the procedure for designing asphalt mixtures that contain recycled-asphalt pavement (RAP). This procedure requires the utilization of several other methods during the design process, including:

Kentucky Method (KM) 64-405, *Extraction of Binder From Asphalt Paving Mixtures*

KM 64-411, *Preparing Ingredient Materials for, and Performing, a Laboratory Mix Design of an Asphalt Mixture*

KM 64-421, *Establishing the Job-Mix Formula of Asphalt Mixtures by the Contractor*

KM 64-433, *Wet-Sieve Analysis of Aggregates Used in Asphalt Mixtures*

KM 64-620, *Wet Sieve Analysis of Fine and Coarse Aggregate*

AASHTO R 30, *Mixture Conditioning of Hot-Mix Asphalt (HMA)*

AASHTO R 35, *Superpave Volumetric Design for Hot-Mix Asphalt (HMA)*

AASHTO T 84, *Specific Gravity and Absorption of Fine Aggregate*

AASHTO T 85, *Specific Gravity and Absorption of Coarse Aggregate*

AASHTO T 209, *Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures*

AASHTO T 316, *Viscosity Determination of Asphalt Binder Using Rotational Viscometer*

ASTM D 5404, *Recovery of Asphalt from Solution Using the Rotary Evaporator*

2. APPARATUS:

2.1. Provide the equipment necessary for the extraction of the asphalt binder from the RAP conforming to KM 64-405 (Method A) with the addition of:

2.1.1. A suitable container for catching the effluent from the centrifuge.

2.1.2. Reagent-grade trichloroethylene (to be used as the extraction solvent).

2.2. Provide the equipment necessary to determine the gradation of each individual virgin aggregate conforming to KM 64-620. Provide the equipment necessary to determine the gradation of the extracted aggregate from the RAP conforming to KM 64-433.

2.3. Provide the equipment necessary for the recovery of asphalt binder from solution by the rotary evaporator method conforming to D 5404.

2.4. Provide the equipment necessary to determine the viscosity of: (1) the asphalt binder recovered from the RAP; and (2) the blended asphalt binder (the virgin asphalt binder plus the asphalt binder recovered from the RAP) conforming to T 316.

2.5. Provide the equipment necessary to perform an asphalt mixture design conforming to R 35.

3. PROCEDURE (RAP, Overall Gradation, and Blended Asphalt Binder Analyses):

3.1. The number of extractions, extracted gradations, and rotary evaporator recovery's required to be performed on the RAP depends on the percentage of RAP in the mixture (by weight of the total mixture). The breakdowns are shown below:

Percentage of RAP in the Mixture	Number of Extractions/Extracted Gradations to be Performed	Number of Rotary Evaporator Recovery's to be Performed
$\leq$ 20	1	0
21 – 30	2	0
$\geq$ 31	3	1

3.2. Oven-dry the RAP to a constant mass at a temperature of 221 $\pm$ 9 ^{o}F, and extract the asphalt binder from the RAP according to KM 64-405 (Method A). Strictly observe those safety precautions mentioned in KM 64-405 with respect to this operation.

3.2.1. Calculate the percentage of asphalt binder in the RAP according to KM 64-405 (Method A). Designate this value as P_{sb} for further calculations. If the percentage of RAP in the mixture requires multiple examinations, average the P_{sb} values from each analysis to obtain one overall P_{sb} for the RAP.

3.2.2. If the percentage of RAP in the mixture requires rotary evaporator recovery testing, retain the effluent from the extraction for further testing.

3.3. Determine the gradation of the extracted RAP aggregate according to KM 64-433. If the

percentage of RAP in the mixture requires multiple examinations, average the gradation values from each analysis to obtain one overall gradation for the RAP.

3.4. If the percentage of RAP in the mixture requires rotary evaporator recovery testing, recover the asphalt binder (extracted from the RAP) from the effluent according to D 5404. Strictly observe those safety precautions mentioned in D 5404 with respect to this operation.

3.5. If the percentage of RAP in the mixture requires rotary evaporator recovery testing, determine the viscosity of the recovered asphalt binder according to T 316.

3.6. Select the percentage of RAP (by weight of the total mixture) to be used in the mixture.

3.7. Determine the gradation of each individual virgin aggregate according to KM 64-620.

3.8. Mathematically blend the virgin aggregates and the RAP aggregate together such that the combined job-mix formula (JMF) is both desirable and feasible. Ensure this JMF satisfies the gradation requirements for the type of mixture specified.

3.8.1. Use the following formula for blending aggregates:

$P = Aa + Bb + Cc + \ldots$, *where*

P	=	the percentage of the combined aggregates passing a given sieve;
A, B, C, ...	=	the percentage of material passing a given sieve for the individual aggregates; and
a, b, c, ...	=	the proportions of individual aggregates used in the combination, where the total equals 1.00.

3.8.2. Since the process of blending aggregates is rather confusing and difficult to explain, especially when RAP is involved, follow the example below.

3.8.2.1. Assume that limestone # 78's, limestone sand, natural sand, and RAP aggregate are blended together to comply with the gradation requirements for a 0.5-in. nominal-maximum mixture. It has already been determined that 31 % RAP is to be used in the mixture. The washed gradations of the individual virgin aggregates and RAP are shown below:

	Limestone # 78's	Limestone Sand	Natural Sand	RAP
Sieve Size	Percent Passing	Percent Passing	Percent Passing	Percent Passing
3/4 in.	100	100	100	100
1/2 in.	95	100	100	90
3/8 in.	72	100	100	65
No. 8	3	70	80	26
No. 16	2	45	50	20
No. 30	2	27	25	15
No. 50	1	20	15	11
No. 200	1.0	12.0	1.0	7.0

3.8.2.2. Since the percentage of RAP aggregate and the individual gradations of all component aggregates (virgin and RAP) are known, the only unknowns are the percentages of the three virgin aggregates. Determining these percentages is largely a matter of "trial-and-error". If the percentages used for the first trial do not satisfy the gradation requirements for the mixture, adjust the percentages until an acceptable result is obtained. Further explanation of the aggregate-blending process is offered in KM 64-421.

For this example, the percentages to be used will be 32 % limestone # 78's, 17 % limestone sand, 20 % natural sand, and 31 % RAP. Using the formula displayed in Subsection 3.8.1 and all known values, determine the combined gradation, for the 3/8-in. sieve, as follows:

P = 72 (0.32) + 100 (0.17) + 100 (0.20) + 65 (0.31) = 80 %.

The following table shows the combined gradation for each sieve for this particular mixture:

	LS # 78's	LS Sand	Natural Sand	RAP		
% in Mix	32	17	20	31		
Sieve Size	Percent Passing	Percent Passing	Percent Passing	Percent Passing	Combined Gradation	Control Points
3/4 in.	100	100	100	100	100	100 min.
1/2 in.	95	100	100	90	95	90 - 100
3/8 in.	72	100	100	65	80	90 max.
No. 8	3	70	80	26	37	28 - 58
No. 16	2	45	50	20	24	
No. 30	2	27	25	15	15	
No. 50	1	20	15	11	10	
No. 200	1.0	12.0	1.0	7.0	4.5	2.0 - 10.0

This blend is certainly not the only one that will satisfy the gradation requirements for a 0.5-in. nominal-maximum mixture, but for the sake of this illustration, this blend will be used in further examples.

3.9. Estimate the total percentage of asphalt binder to be used in the RAP mixture by using the following empirical formula:

$$P_b = 0.035a + 0.045b + Kc + F, \text{ where}$$

P_b = the approximate, total asphalt binder demand of the mixture;
a = the percent of aggregate retained on the No. 8 sieve;
b = the percent of aggregate passing the No. 8 sieve and retained on the No. 200 sieve;
c = the percent of aggregate passing the No. 200 sieve;
K = 0.15 for 11 - 15 percent passing the No. 200 sieve,
0.18 for 6 - 10 percent passing the No. 200 sieve, and
0.20 for 5 percent or less passing the No. 200 sieve; and
F = 0 - 2.0 percent (based on absorption of light or heavy aggregate).
In the absence of other data, use a value of 0.7 for F.

For example, using the combined gradation as shown in Subsection 3.8.2.2, determine the approximate total asphalt binder demand of the mixture by the following:

$$P_b = 0.035\ (63.0) + 0.045\ (32.5) + 0.20\ (4.5) + 0.7 = 5.3\ \%.$$

3.10. To select the appropriate grade of virgin asphalt binder to blend with the RAP in order to obtain a blended asphalt binder that satisfies the requirements of the grade for the specified mixture, follow the directions given in Subsection 409.03 of the Department's *Standard Specifications*. When using 31 percent or more RAP in the mixture, select the binder grade for the virgin asphalt binder using the following procedure:

3.10.1. From the mixture's bid item, determine the grade of asphalt binder specified. Then, determine the range of acceptable viscosities for that grade from the table below. This information is necessary to ensure the viscosity of the blended asphalt binder (the recovered asphalt binder plus the virgin asphalt binder) satisfies the requirements of the grade specified for the mixture in question.

PG Binder Type	Range of Viscosity from T 316 (Pa·s)
PG 58-22	0.26-0.35
PG 64-22	0.36-0.58
PG 70-22	0.59-0.90
PG 76-22	0.91-3.35

3.10.2. Determine the viscosity of the recovered asphalt binder from the RAP according to T 316.

3.10.2.1. Determine the viscosity of the virgin asphalt binder to be blended with the recovered asphalt binder from the RAP to result in a combined asphalt binder that will satisfy the specifications as determined in Subsection 3.10.1 by following the directions given below:

3.10.2.1.1. Estimate the percent of virgin asphalt binder to be added to the total mixture by using the following formula:

$$P_{nb} = \frac{(100^2 - rP_{sb})P_b}{100(100 - P_{sb})} - \frac{(100 - r)P_{sb}}{100 - P_{sb}}, \textit{ where}$$

P_{nb} = the percent of virgin asphalt binder in the mixture;
r = the virgin aggregate expressed as a percent of the total aggregate in the mixture;

P_b = the estimated, total asphalt binder demand of the mixture in percent (Subsection 3.9); and

P_{sb} = the asphalt binder content (AC) of the RAP in percent (Subsection 3.2). For example, suppose the AC of the RAP, P_{sb}, in a 0.5-in. nominal-maximum mixture is 5.6 % and the mixture contains 31 % RAP, then:

$$P_{nb}=\frac{[100^2-69(5.6)]5.3}{100(100-5.6)}-\frac{(100-69)5.6}{100-5.6}=3.5\%.$$

3.10.2.1.2. Calculate the ratio of virgin asphalt binder, P_{nb} (as a percentage), to the total AC of the mixture, P_b, by using the following formula:

$$R_1=\frac{100\,P_{nb}}{P_b}.$$

For example, given the mixture described in Subsection 3.10.2.1.1, the ratio, R_1, of the virgin asphalt binder to the total asphalt binder is:

$$R_1=\frac{100(3.5)}{5.3}=66.9\%.$$

3.10.2.1.3. Determine the grade of virgin asphalt binder to be used in the blend by using the following formula:

$$10^{\log Vr-\frac{100\,(\log Vr-\log Vb)}{R_1}},\ where$$

V_r = the viscosity of the recovered RAP asphalt binder from T 316 (Pa·s);

V_b = the desired viscosity of the virgin asphalt binder and RAP asphalt binder blend from Subsection 3.10.1 (Pa·s); and

R_1 = the ratio of the virgin asphalt binder to the total asphalt binder (Subsection 3.10.2.1.2).

For example, consider the mixture described in Subsections 3.10.2.1.1 and

3.10.2.1.2. The desired viscosity of the blend is that of a PG 64-22 (0.36 - 0.58 Pa·s), and the viscosity of the recovered RAP asphalt binder (Subsection 3.10.2) is 1.52 Pa·s. Determine the viscosity of the virgin asphalt binder required to produce a blend of asphalt binder with a viscosity of 0.36 to 0.58 Pa·s (target value of 0.47 Pa·s) as follows:

$$10^{\log(1.52)-\frac{100[\log(1.52)-\log(0.47)]}{66.9}} = 0.26\ Pa \cdot s$$

In this case, with the viscosity's being 0.26 Pa·s, a PG 58-22 (0.26 - 0.35 Pa·s) would be blended with the RAP asphalt binder to produce a blended asphalt binder that would be within acceptable tolerances for a PG 64-22.

3.10.2.2. Blend a sample of appropriate size for the battery of analyses described in the following Subsection 3.10.2.3, by weight, of the virgin asphalt binder and recovered asphalt binder at percentages corresponding, respectively, to the values for R_1, as given in Subsection 3.10.2.1.2, and R_2, as given below:

$$R_2 = 100 - R_1.$$

For example, since R_1 is 66.9 % as determined in Subsection 3.10.2.1.2, R_2 would be 33.1 %. Therefore, blend a sample of appropriate size containing 66.9 % of the virgin asphalt binder, by weight, and 33.1 % of the recovered (or RAP) asphalt binder, by weight.

3.10.2.3. Analyze the sample of blended asphalt binder for viscosity according to T 316 (Subsection 3.5). This examination is necessary to verify that the blended asphalt binder satisfies the viscosity range of the grade of asphalt binder specified for the particular mixture (as given in Subsection 3.10.1).

3.10.2.4. After verifying that the blended asphalt binder and the gradation of the combined virgin and RAP aggregates satisfies all applicable specifications, determine the JMF according to KM 64-421.

4. PROCEDURE FOR MIX DESIGN -

4.1. Analyze the mixture, including the RAP, for aggregate properties according to R 35. Generate, by extraction, an adequate amount of RAP aggregate to blend with the virgin aggregates to obtain samples for aggregate consensus properties.

4.1.1. When the RAP contains coarse aggregate, combine the coarse RAP aggregate with

the coarse virgin aggregates in the proper proportion. Analyze the blend for coarse-aggregate angularity and flat-and-elongated particles according to R 35.

4.1.2. When the RAP contains fine aggregate, combine the fine RAP aggregate with the fine virgin aggregates in the proper proportion. Analyze the blend for fine-aggregate angularity according to R 35. The Department will not require fine RAP aggregate to be included in the sample tested for sand equivalency.

4.2. Analyze the mixture, including the RAP, for volumetric properties according to R 35.

4.2.1. Use the formulas given in the following subsections to calculate the correct weights for the "specimen-batching" process.

4.2.1.1. To calculate the total specimen weight, use the following formula:

$$W_{ts} = W_{ta} + \frac{W_{ta} P_r P_{sb}}{100^2}, where$$

W_{ts} = the total specimen weight (the virgin aggregate + RAP) in g;
W_{ta} = the total aggregate weight (the virgin aggregate + RAP aggregate), estimated from past mix-design experience or by making test specimens to achieve a height of approximately 115 mm, in g;
P_r = the percentage of RAP in the mixture; and
P_{sb} = the AC of the RAP (Subsection 3.2), in percent.

For example, if 4500 g of total aggregate are required to produce a specimen having a height of 115 mm, calculate the total specimen weight (without the virgin asphalt binder) as follows:

$$W_{ts} = 4500 + \frac{4500(31)(5.6)}{100^2} = 4578\ g.$$

4.2.1.2. To calculate the weight of virgin aggregate in each specimen, use the following formula:

$$W_{va} = W_{ta} - \frac{W_{ta} P_r (100 - P_{sb})}{100^2}, where$$

W_{va} = the virgin aggregate weight in g.

For example, consider the weight for W_{ta}, as shown in Subsection 4.2.1.1. The weight of virgin aggregate is equal to:

$$W_{va}=4500-\frac{4500(31)(100-5.6)}{100^2}=3183\ g.$$

After determining the weight of virgin aggregate required for each specimen, proportion that value appropriately among each applicable sieve size for the mixture in question, after accounting for the "dry-sieve versus wet-sieve" correction, as described in KM 64-411. Use the same procedure as described in KM 64-411 to "weigh up" the virgin-aggregate portion of each mix-design specimen.

4.2.1.3. To calculate the total weight of RAP required for each specimen, use the following formula:

$$W_{tr} = W_{ts} - W_{va}, \textit{ where}$$

W_{tr} = the total weight of RAP in g.

For example, knowing the total specimen weight (without the virgin asphalt binder) and the virgin aggregate weight, the total weight of RAP to be included in each specimen is:

$$W_{tr} = 4578 - 3183 = 1395\ g.$$

After determining the weight of RAP required for each specimen, "weigh out" that value of the total RAP sample, and add it to the virgin-aggregate portion. Ensure that a representative sample of RAP is obtained for each specimen.

4.2.1.4. To calculate the amount of virgin asphalt binder added to each specimen to achieve the desired total AC, use the following formula:

$$W_{vb}=W_{ta}-W_{ts}+\frac{W_{ta}\,P_{tb}}{100-P_{tb}},\textit{where}$$

W_{vb} = the weight of virgin asphalt binder in g; and
P_{tb} = the percentage of total asphalt binder in the specimen.

For example, suppose that a total AC of 5.0 % is desired for each specimen. The weight of virgin asphalt binder to be added to the virgin aggregate and RAP is:

$$W_{vb}=4500-4578+\frac{4500(5.0)}{100-5.0}=159\ g.$$

After determining the weight of virgin asphalt binder required for each specimen, introduce that value to the virgin-aggregate and RAP portions of the specimen. Heat the virgin aggregate and asphalt binder to the mixing temperature prior to the mixing process. Heat the RAP to a temperature of 230 ± 5 ^{0}F for no more than two hours. Exercise great care in order to prevent overheating the RAP. Conform to the mixing temperature given in KM 64-411 for the PG binder specified in the mixture's bid item. Do not reheat previously heated RAP to use it again.

After laboratory mixing and prior to compaction, short-term condition the mixture of virgin and RAP material according to R 30. Use the same short-term conditioning procedure for the specimens containing RAP as for a mixture containing all virgin materials. Conform to the compaction temperature given in KM 64-411 for the PG binder specified in the mixture's bid item.

4.2.2. To evaluate the mixture for the percentage of voids-in-mineral aggregate (% VMA) and percentage of voids filled with asphalt (% VFA), calculate the combined bulk specific gravity, G_{sb}, of the aggregate (virgin aggregate and RAP aggregate).

4.2.2.1. Determine the bulk specific gravity of each individual virgin aggregate according to T 84 and T 85, as applicable.

4.2.2.2. Estimate the bulk specific gravity of the RAP by following the directions given below:

4.2.2.2.1. Determine the theoretical maximum specific gravity of at least two representative samples of the RAP according to T 209. Perform the *Supplemental Procedure for Mixtures Containing Porous Aggregate* from T 209 on each sample. Average the results of the two samples to obtain the value for further calculations.

4.2.2.2.2. Determine the effective specific gravity of the RAP aggregate, G_{se}, by using the following formula:

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

G_{mm} = the theoretical maximum specific gravity of the

RAP aggregate (Subsection 4.2.2.2.1);

P_b = the AC of the RAP in percent; and

G_b = the specific gravity of the RAP asphalt binder (usually 1.03).

4.2.2.2.3. Estimate the amount of absorbed asphalt, based on experience, and "back-calculate" the bulk specific gravity of the RAP aggregate. Determine the bulk specific gravity, G_{sb}, of the RAP aggregate using the following formula:

$$G_{sb} = \frac{100\,G_{se}\,G_b}{P_{ba}\,G_{se} + 100\,G_b}, where$$

G_{se} = the effective specific gravity of the RAP aggregate (Subsection 4.2.2.2.2); and

P_{ba} = the percentage of absorbed asphalt in the RAP, by weight of the total aggregate.

If the P_{ba} cannot be determined or reasonably estimated, use a value of 0.5 %.

For example, consider RAP that has a G_{mm} of 2.450 and an asphalt binder content, P_{sb}, of 5.6 %, as explained in Subsection 3.10.2.1.1. Estimate its G_{sb} as follows:

$$G_{se} = \frac{100 - 5.6}{\frac{100}{2.450} - \frac{5.6}{1.03}} = 2.668$$

If the estimated P_{ba} is 0.5 %, using the formula given in Subsection 4.2.2.2.3:

$$G_{sb} = \frac{100\,(2.668)(1.03)}{0.5\,(2.668) + 100\,(1.03)} = 2.634$$

Utilize this G_{sb} value for the RAP, along with the G_{sb} values of each individual virgin aggregate described in Subsection 4.2.2.1, to obtain a combined G_{sb} for

the entire mixture. Further utilize this value, calculated according to R 35, for % VMA and % VFA determinations.

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